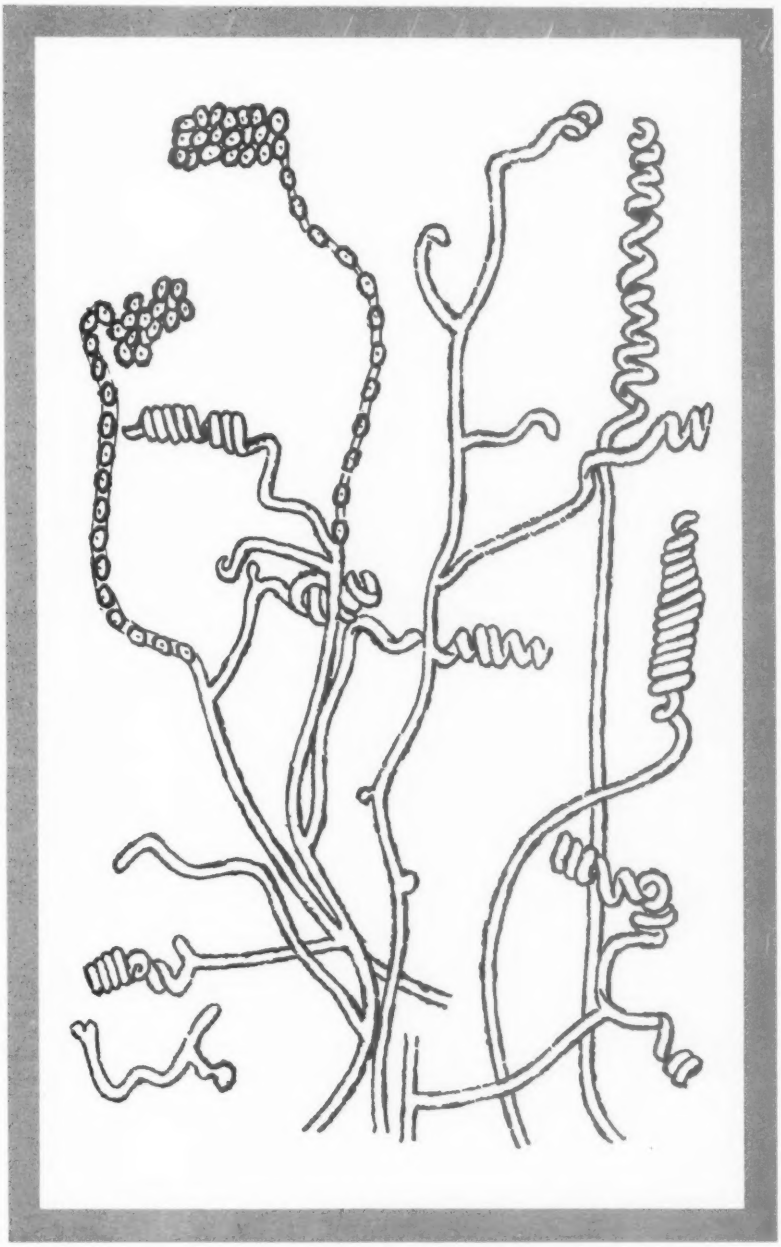
AGRICULTURAL

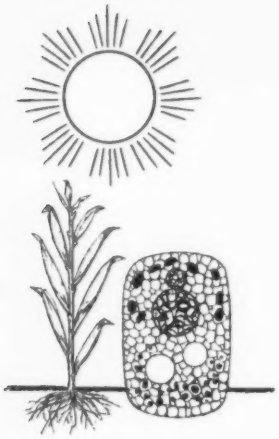
Science Review

COOPERATIVE STATE RESEASCH SERVICE U.S. DEPARTMENT OF AGRICULTURE VOL. 4, NO. 2



SECOND QUARTER 1966

MICROBES AND THE SURVIVAL OF MAN ON EARTH



AGRICULTURAL SCIENCE REVIEW

Second Quarter 1966 Vol. 4 No. 2

CONTENTS

1 MICROBES AND THE SURVIVAL OF MAN ON EARTH
15 WATER DEVELOPMENT
22 AGRICULTURAL RESEARCH: A KEY TO UNDERSTANDING OUR ENVIRONMENT
28 THE AGRARIAN TRADITION
33 FUNDAMENTAL RESEARCH AND PROGRESS
37 ORGANIZING RESEARCH FOR SOCIAL AND ECONOMIC OBJECTIVES

EDITORIAL BOARD

J. G. HORSFALL, Director, Connecticut Agricultural Experiment Station; D. W. THORNE, Director, Utah Agricultural Experiment Station; W. E. KRAUSS, Associate Director, Ohio Agricultural Experiment Station (Alternate); H. A. RODENHISER, Deputy Administrator, Agricultural Research Service; GEORGE M. JEMISON, Deputy Chief, Forest Service; R. G. GARNER and T. S. RONNINGEN, Cooperative State Research Service.

EDITORIAL CONSULTANTS

W. H. CUMMINGS, J. F. SYKES, and ROLAND R. ROBINSON, Cooperative State Research Service.

EDITOR: WARD W. KONKLE

Man And His Environment

Discerning readers will no doubt observe a common thread linking the articles in this issue of *Review*—man's ever-quickening search to learn more about his environment while there is yet time to manipulate it wisely and skillfully to his advantage. This search may seem exasperatingly slow in some areas; in other areas we are accumulating knowledge so rapidly that we must employ electronic computers to maintain some semblance of order and understanding. Goading us on, perhaps, is the uneasy feeling rooted to two conditions that certainly were not wholly unexpected—overpopulation and the pollution and waste of nonrenewable resources. Amidst it all, however, is the happy thought that one success begets another. Such a theorem unquestionably must help to spawn the optimism so noticeable among the leading thinkers of our times—some of whom speak from these pages. For what it's worth, the gloom painters are far outranked by men of hope and faith.

Lest we become too complacent, however, we may need to be reminded that there are still a number of problems hanging around that need some imaginative thinking not heretofore brought to bear. For example, one of our authors hints at the possible catastrophe if some destructive pathogen suddenly sought as its host the rice plant—on which half the world depends for major sustenance. Such an agrarian dependence, this author views as highly questionable.

Another problem also identified in this issue is the paucity of our knowledge of the insect world—a condition that with the advent of intensified agriculture forced us to rely too heavily on costly (and incautious, perhaps) methods of destroying destructive species. Fortunately, the new look in this discipline is most encouraging—late though it may be.

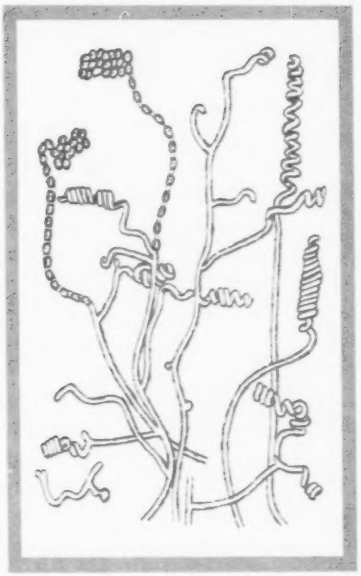
Hopefully, as man continues to exert more control over his environment, he can do so with a degree of sophistication yet undreamed of.

AGRICULTURAL SCIENCE REVIEW is published quarterly by the Cooperative State Research Service, U.S. Department of Agriculture, Washington, D.C. 20250.

Information in this magazine is not copyrighted and may be reprinted without permission. Mention of the source will be appreciated but is not required.

Microbes and the Survival of Man on Earth

SELMAN A. WAKSMAN



THE productivity of the land depends to a varying degree upon several distinct contributing elements—the soil, the microbe, and the husbandman. Although the significance of the first and the last has been known since ancient times, the microbes, or those microscopic forms of life that inhabit the earth, have become recognized only in recent years as highly important agents responsible for many of the reactions essential in soil processes and in the cycle of life upon this earth. This was well expressed by the great master of soil microbiology, Winogradsky (*30*) [1] who, in summarizing his own interests in soil microbes during a period of 50 years, has said:

"L'origine lointaine de cette branche nouvelle de la grande science microbiologique est à chercher dans les idées de Pasteur sur le rôle des 'infiniment petits' dans la nature. D'un autre côté, il est évident que la recherche des agents vivants devait être précédée par la connaissance des phénomènes qui se déroulent dans le milieu naturel." [2]

[1] Italic numbers in parentheses refer to Literature Cited, p. 14.

[2] "The early origin of this new branch of the great science of microbiology is to be looked for in the ideas of Pasteur on the role of the 'infinitely small' in nature. On the other hand, it is evident that the study of living agents must be preceded by a knowledge of the phenomena that occur in a natural medium."

THE SOIL—MOTHER EARTH—THE LAND

IN whatever terms we consider the *pedus* or the soil under our feet—whether we think of it as mother earth or the mystical concept from which man has arisen or whether we conceive of it as of land that grows our crops to feed us and our domesticated plants and animals, we are always certain that we are dealing with one of the basic elements essential for the support of human and animal life on this planet. The soil is not a mass of rocks and rock residues; it is not a dead organic-inorganic system, but a living system teeming with numerous forms of life. These range from the microscopic bacteria and fungi, algae and protozoa, to the larger worms and insects, and finally include also the root systems of plants and burrowing animals. One may further mention the presence of ultra-microscopic particles in the soil—the viruses and phages—which are intricately bound with the living cells.

Hilgard (*10*), one of the early students of soil science in this country, defined a soil as "the more or less loose and friable material in which, by means of their roots, plants may or do find a foothold and nourishment, as well as other conditions of growth." The Russian school of pedologists considered the soil as a natural body rather than as a

geological layer; its properties depend not only on the parent material but also on the climatic (atmospheric) agencies and the participation of plants and animals. The importance of the living elements in soil formation, including the role of microbes, is now universally well established: It consists in breaking up the raw materials which are present or brought into the soil, and in transforming them into forms available as food for plants.

The underlying rocks serve as the basic elements that give rise, at their very surface, to the mass of disintegrated materials, which gradually, as a result of the numerous factors listed above, produce a soil. The weathering of the rocks covered a span of many thousands of years. Plant growth contributes in no small measure to this weathering process. The chemical composition and the physical nature of the underlying rocks define the minerological makeup and the structure of the soil. The climatic factors, notably rainfall and temperature changes, contribute to the processes of weathering of the rocks and the translocation of their chemical constituents through the several surface layers, resulting in the formation of a typical soil structure.

Plant vegetation, through the mechanical action of its root system and the dissolving and transforming effects of its chemical constituents, further influences the nature and composition of the soil produced. The numerous groups of living microbes as well as various forms of plant and animal life inhabiting the surface layers of the soil contribute further toward making, out of a mass of dead mineral and organic debris, a fertile soil, in which the elements essential for continued plant life are kept in constant circulation.

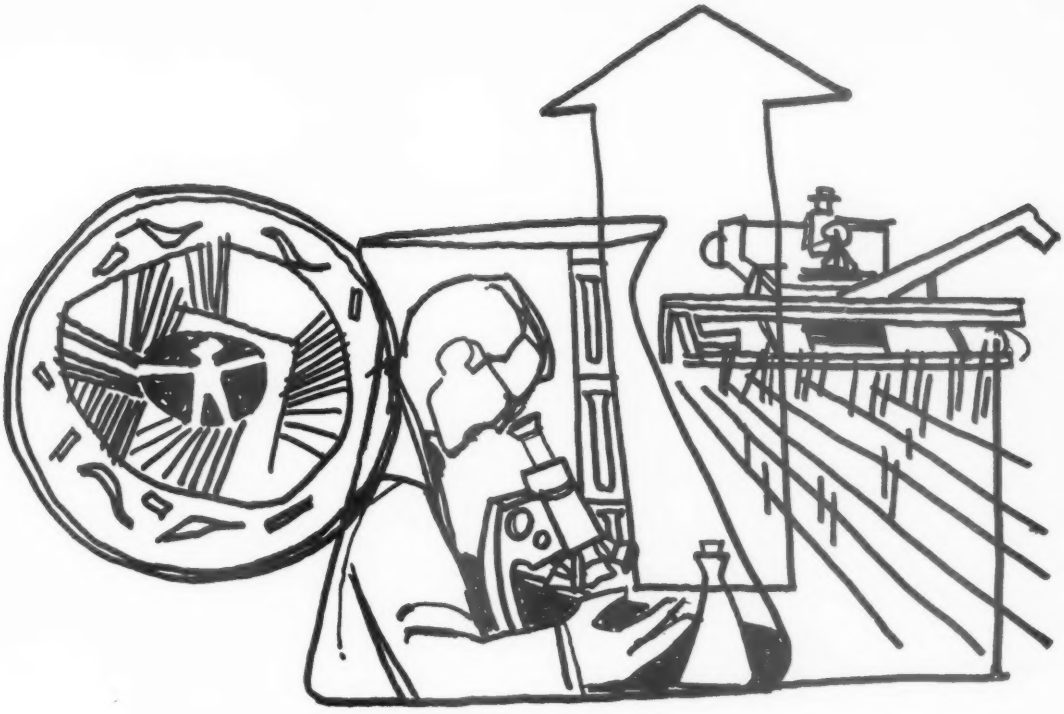
Thus, soil is distinct from the rock from which it was formed. It has become finely pulverized and altered through the influence of climatic and atmospheric agents, and through the effects exerted by both higher and lower plant and animal life, whereby it has gained an important constituent which distinguishes a soil sharply from a mass of rock debris. This constituent is humus. The microbial population characterizes the soil not only through its various activities, but also through the mass of cell material which permeates its environment. The soil is thus to be considered not only from a structural viewpoint but from a functional one, not only as a mass of inanimate material but as a living system, not only in a static condition but in a dynamic state, not only as a branch of geology or surface geology but as a natural biological environment.

The fertility of the soil, or its crop-producing capacity, depends entirely upon a combination of all the preceding factors. Each is essential in making the soil what it is. Each makes its particular contribution towards making a soil fertile or unfertile, productive or nonproductive—the differences between the two being only a matter of degree rather than of kind.

The concept of soil fertility cannot be sufficiently understood without proper appreciation of the nature, origin, and function of the soil humus. This term is used to designate the dark-colored organic matter not only of the soil, but also of peat bogs, water basins, and composts. Humus originates in nature from the decomposition of various plant and animal residues by micro-organisms. Its physical and chemical properties vary considerably, depending upon the nature of the plant materials, the micro-organisms active in the decomposition processes, and conditions of decomposition, notably moisture, temperature, aeration, reaction, and inorganic materials.

Humus is not a simple compound, nor is it a well-defined group of compounds. It varies considerably in its physical and chemical properties, its effect upon the soil, and its relation to plant growth. It possesses certain well-defined characteristics—a dark color, a high carbon and frequently a high nitrogen content, a considerable buffering and moisture-holding capacity, and the ability to absorb much heat and to combine with basic materials. The microbial population of the soil plays an important role in the formation of humus, as well as in its slow decomposition, when the various chemical elements stored in the humus are made available for new plant growth. The rate of decomposition of humus and the liberation of nutrient elements depend largely upon the origin and nature of the humus.

Since ancient times the humus of the soil had been considered as synonymous with its fertility and was often spoken of as the "fat of the land." However, its exact chemical nature and its role in plant nutrition were only vaguely understood. In the early part of the 19th century, with the beginnings of our knowledge of modern chemistry, all organic substances were looked upon as simple in composi-



tion, similar to inorganic materials. Humus was considered to be made up of a few dark-colored compounds, designated as "humic acids." More recently, it was recognized that humus is a natural body and that its formation, as well as its nature and abundance, depend upon the character of the surface vegetation, the treatment of the soil, and the various environmental conditions, such as climate and topography. Even if humus is not the major and direct source of nutrients for plants, it was shown to represent an accumulation of various chemical elements and compounds that are essential for the growth of higher plants. These elements become available to plants when the humus is decomposed through the action of the numerous soil-inhabiting microbes.

Although it has now been definitely established that plants do not feed directly upon humus, it performs numerous functions in soil processes and in plant growth. I need hardly emphasize here its mechanical, physical, and chemical effects upon the soil which may be summarized as follows: Improving soil structure, increasing its water-holding capacity and its buffering properties; providing better aeration and exerting a binding effect upon its constituent particles; providing a more favorable medium for the development of the root systems of growing plants; rendering many elements more soluble and neutralizing the effect of substances which tend to be toxic to plants; favoring the growth of the numerous microbes which constantly work over the soil materials rendering the nutrient elements more suitable for plant growth; serving as a storehouse of plant nutrients, the gradual decomposition of which leads to the liberation of a continuous stream of carbon as carbon dioxide, of nitrogen as ammonia which is soon changed to nitrate, and of phosphorus as phosphate.

The activities of millions of microbes which inhabit every soil particle are thus closely bound with the function of the humus. Even the living and dead cells of the microbes, such as the mycelium of fungi and actinomycetes, the slimy substances of bacteria, and their decomposition products, act as soil-binding agents. At certain stages of decomposition of the organic matter added to the soil, the humus is most active in bringing about a binding or aggregating effect upon the soil particles.

Various other contributing factors must be considered in soil formation and in its final productivity. Of special importance are various other biological factors, such as the presence of plant-pathogenic fungi and crop-destroying insects, the growth-stimulating effects of various microbes and their complex interrelationships. The *soil* can now be considered as *land* upon which man lives and from which he derives his sustenance.

THE MICROBE

IN addition to the role that microbes play in the transformation of elements in nature and especially in the soil, they affect in numerous other ways man's struggle for existence and his very survival upon this earth. These functions can be broadly divided into the following categories:

1. The causation of numerous infectious diseases of man, animals, and plants—diseases that may often reach epidemic proportions. This field of activity is beyond the scope of this survey. It may only be mentioned here as occupying an important place among the many and varied activities of microbes. It is important to note that the soil harbors certain disease-producing organisms, such as the tetanus bacillus, and toxin-producing organisms, such as *B. botulinus,* aside from the numerous microbes capable of causing plant diseases.

2. The destruction of human dwellings, notably wooden structures, various forms of clothing, and of other products essential in the life of man. Here the soil, even more than in the previous category, is a direct source of bacteria and fungi that are responsible for causing such damage.

3. The destruction of waste products of plant and animal life in the soil. These activities lead, on the one hand, to the formation of the more or less stable humus, and, on the other hand, to the liberation of the various elements essential for the continuation of life on this planet. Microbes bring about in soils and in water basins numerous other chemical reactions that involve processes of oxidation and reduction, fixation of atmospheric nitrogen, transformation of sulfur, and a variety of other reactions, which tend to increase and make available the supply of nutrient elements essential for plant and animal life. In carrying out these reactions, microbes synthesize considerable quantities of cell material which contributes further to the formation and accumulation of humus. The humus, in turn, serves both as a reservoir of plant nutrients and brings about the improvement of the condition of the soil, thus making it a more suitable medium for plant and animal life. Similar processes take place in rivers, lakes, and seas, which, in many respects, parallel those taking place in the soil.

4. Processes of purification of human and animal wastes commonly known as sanitation. When controlled by man, these processes serve to prevent the spread of human and animal diseases and result in the destruction of the disease-producing agents. The reactions involved parallel those taking place in soils and in water basins, contributing further towards the cycle of life on this planet.

5. The preparation of foodstuffs and beverages, comprising grain products (bread making), milk and milk products, as well as fruit and vegetable products. The production of wines, beers, and a variety of distilled beverages belongs to this category.

6. Industrial fermentations, ranging from the production of various acids and alcohols to special processes involving the manufacture of vitamins, enzymes, hormones, and a number of important processes essential to the life of man.

7. Numerous groups of soil- and water-inhabiting microbes—bacteria, actinomycetes and fungi—are capable of producing certain chemical substances known as antibiotics that have the capacity to destroy disease-producing bacteria and other human and animal pathogens. They are now occupying an important place in the treatment of a number of human, animal, and plant diseases, notably those caused by bacteria, certain fungi, and protozoa. Some of these antibiotics are able to exert a growth-promoting effect upon poultry and other domestic animals, and have thus found a place in animal feeding. They are used in the preservation of various foodstuffs, such as those that are boiled prior to consumption. Finally, they have found an important place as preservatives of virus preparations, of tissue cultures, and of a variety of other biological materials.

8. Microbes play an important role in numerous other processes. It is sufficient to mention such diverse processes as retting, food spoilage and deterioration, biological control of insects and rodents,

and the use of certain microbes as sources of proteins, amino acids, and fats.

9. Not the least important place is that gained by microbes as models for the study of biochemical reactions, thus facilitating greatly an ever-growing understanding of the mechanism of living processes and of life itself.

THE SOIL MICROBES

THE soil contains a characteristic microbial population which is quite distinct from that of other natural media such as seas, lakes, and river basins.

This soil population plays an important part in the decomposition of plant and animal residues and in the liberation of nutrient elements in available forms--especially in the formation and decomposition of humus and in the transformation of the mineral soil constituents. Some of the microbiological processes in the soil involve nitrogen transformation and comprise such processes as nitrogen liberation, nitrogen accumulation, nitrogen fixation, and nitrate reduction. The sulfur transformations also comprise a variety of reactions, including oxidation and reduction.

The survival of microbes added to the soil—comprising both those injurious to human health, such as the typhoid and tuberculosis bacteria, and those that are beneficial to human economy, such as legume bacteria and mycorrhiza fungi—present specific problems related to the soil population. This is also true of the relation of the microbes inhabiting the soil to the growth of higher plants, especially the interaction between microbes and the root systems of plants, and the relation of microbes to soil fertility. Finally, and most important, one is concerned with the role of microbes in soil formation and soil deterioration.

Microbes inhabiting the soil do not live in watertight compartments or in pure cultures, although there are conditions which favor the growth of one kind of organism over others, thus giving rise to colonization effect. This was well recognized by the early soil microbiologists. Lipman (*13*) emphasized that "There are species of bacteria so common in cultivated soils as to constitute a definite bacterial flora. This flora may vary with climatic conditions, the composition of the soil, and the methods of tillage and cropping. However, it shows fairly constant characteristics." Russell and his collaborators (*20*) also recognized the fact that "there is a close relationship with vegetation, the soil population being dependent almost entirely on the growing plant for energy material, while the plant is equally dependent on the activities of the soil population for removing the residues of previous generations of plants and for the continued production in the soil of simple materials, such as nitrates, which are necessary to its growth."

Some of the soil processes are not due to the activities of single kinds of microbes, but to a number of different forms; it may thus be difficult to establish the role of a particular organism in a certain process. The decomposition of cellulose can be brought about by many kinds of bacteria, by various fungi and actinomycetes, by certain protozoa and other invertebrates. The same is true of the decomposition of proteins, hemicelluloses, and other organic compounds. Some of these processes may be brought about in chainlike reactions, where one organism uses the products of another, where one reaction leads to another, where the activities of one form depend entirely upon those of others. Proteins are decomposed to ammonia by certain organisms; ammonia is oxidized by others to nitrate; still others are capable of reducing this compound under certain conditions to nitrite, ammonia, and atmospheric nitrogen.

The nature of the soil microbiological population varies greatly depending on the composition of the soil, climatic conditions, plant vegetation, and methods of soil treatment. This population consists of microbes varying in size from microscopic and ultramicroscopic forms to macroscopic organisms. They also vary in the nutrients required and in their metabolic activities. Some are autotrophic, utilizing carbon dioxide for synthesis of organic materials; energy may be obtained from sunlight through their ability to produce chlorophyll or by simple oxidation processes as that of sulfur and ammonia. Other organisms are heterotrophic, depending for their energy needs upon organic materials performed by plants, animals, or other microbes.

Soil microbes vary in their resistance to heat. Most are mesophilic; a few are thermotolerant or thermophilic. They also vary in their oxygen requirements; some are anaerobic and are able to lead a normal life in the complete absence of free oxygen; others are aerobic, requiring oxygen. A

few are able to utilize the gaseous nitrogen of the atmosphere; the majority of microbes, however, require combined nitrogen for their nutrition, either in an organic or inorganic form.

Some of the soil microbes are pathogenic to plants or animals; most of them are saprophytic. Some are predaceous, feeding on other microbes. Some live within the root systems of plants and animals and are responsible for various symbiotic relationships. The great majority of them are able to attack dead organic residues.

Some of the soil microbes produce chemical substances that have the capacity to inhibit the growth of other microbes and even to destroy them. Some are able to form compounds that are toxic to plant growth; others produce substances that stimulate plant growth.

This, then, is the world of the soil microbes. They live, reproduce, and die in the soil as their natural habitat. Some have the power of locomotion; others are nonmotile and form colonies or zooglea around soil particles. Some produce an extensive branching mycelium which surrounds the soil particles and clumps them together into a porous mass of material. The extent of their multiplication and growth depends entirely upon the available food supply. They render the soil truly a living system. Without them, the soil would remain a mass of dead organic and inorganic debris. Without their continuous activities, the cycles of life would soon come to a standstill.

One can hardly attempt to list here all the families and genera of microbes found in the soil. It would be even more difficult to list the great variety of activities that these microbes are able to carry out, their power of adaptation to different environments, and their capacity of mutation under certain conditions. It has been said that you can isolate from the soil any microbe that would be able to carry out a certain desired reaction, provided conditions are made favorable for the development of such microbes. The classical method for the isolation of microbes by the soil enrichment procedure is based upon the following principle: You enrich the soil with a given chemical substance and keep it at a favorable temperature and moisture. Before long, in response to such treatment, specific microbes will develop that have the capacity to bring about the desired transformation of the particular substance.

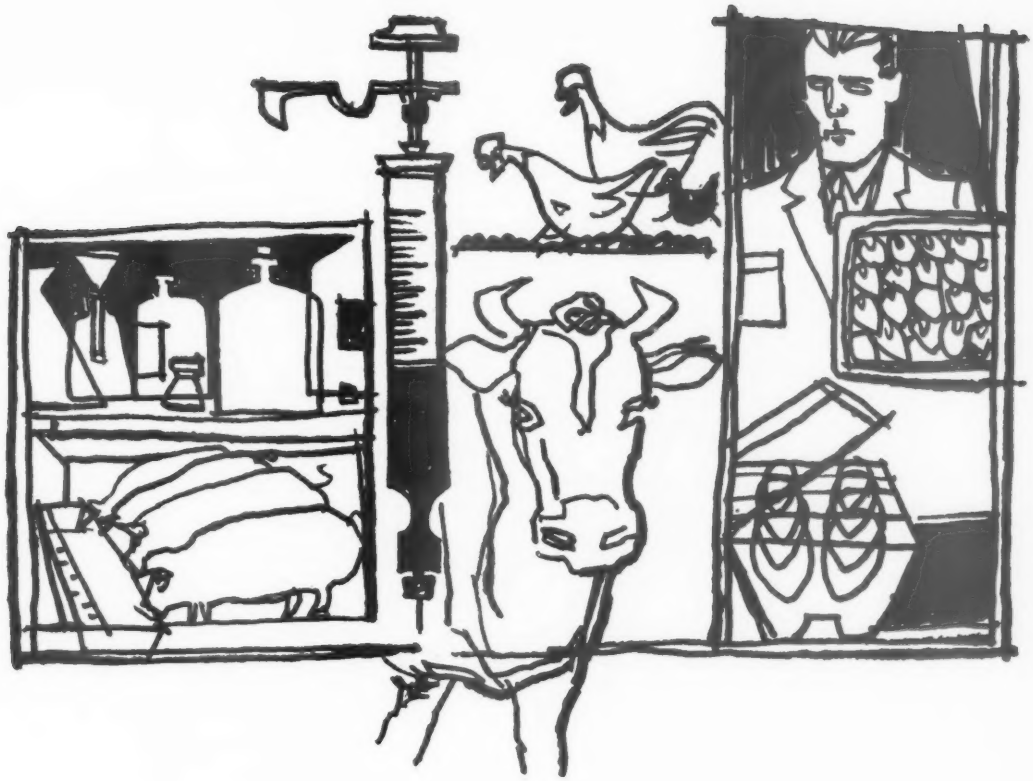
The work of Beijerinck (*1*) and Winogradsky (*30*) made the enrichment method famous. Numerous nitrifying and nitrogen-fixing bacteria, starch-liquefying and cellulose-decomposing organisms, hydrocarbon-oxidizing, and a variety of other bacteria and fungi were isolated from the soil and other natural substrates by the use of this method. In an attempt to find bacteria capable of destroying the capsular carbohydrate of the pneumococcus, Dubos (*7*) utilized this method rather successfully; the bacteria thus isolated from the soil yielded an enzyme capable of hydrolyzing this carbohydrate to the constituent sugars and sugar acids.

To examine all the complex relationships between the microbes and higher forms of life, including both plants and animals and man himself, would require far more space than a brief article would allow. Attention may merely be called to certain recent developments in the field. I have in mind the growing knowledge of microbial interrelationships in a complex population, and particularly the accumulated information of one group of soil-inhabiting microbes, the actinomycetes, and their capacity (as well as that of certain other soil-inhabiting organisms) to produce a group of chemical compounds known as antibiotics.

Microbial Interrelations

EACH of the microbial processes mentioned in the preceding section fails to elucidate individually the complexity of the soil population with it numerous interrelationships. Microbes may assist one another in preparing the required nutrients; they may compete with one another not only for available foodstuffs, but also by exerting a variety of injurious effects upon one another. Some microbes produce growth-stimulating substances; others produce substances injurious to microbial growth, the latter comprising the antibiotics and lytic agents.

The numerous interrelations in a complex microbiological population include the following: (a) associations and antagonisms in the utilization of nutrients or foodstuffs; (b) competition for available space; (c) effect of environmental conditions upon specific groups of micro-organisms; (d) relationships among microbial strains belonging to the same species, and among individuals belonging to different species, as well as competition between the different cells within a given culture; (e) relation-



ships between young, growing, and reproducing cells, and older or resting cells; (f) relationships between microbial strains immune or resistant to certain agents and those that are less resistant or more sensitive; (g) relationships between microbes that can find protection in the cells of higher forms of life (either symbiotic or injurious to the latter), as in the root-nodule bacteria or mycorrhiza-producing fungi, on the one hand, or of intracellular pathogens and the host cells, on the other; (h) relationships among micro-organisms possessing the capacity to attack other living organisms, namely parasites, and organisms that obtain their nutrients from simple elements and compounds or from dead organic residues such as saprophytes.

In trying to analyze the phenomena of association and antagonism among microbes, I emphasized in 1937 (*23*) the fact that nature provides numerous complex relationships among living systems. I said: "Among the most significant of these are the effects of lower or microscopic forms of life upon higher plants and animals and upon one another. The production by micro-organisms of toxins comprises specific effects, either favorable or unfavorable." Various attempts have been made to read into the ability of soil microbes to produce such toxic substances or antibiotics, as they later became known, as broad phenomena controlling the life of microbes in the soil if not in nature as a whole. These ideas may be now considered as largely teleological concepts, especially as regards their potential significance in soil processes. Evidence has been presented (*26*) that, with few exceptions, such generalizations are not justified.

In speaking of the microbe as a biological system (*24*), I said just about a quarter of a century ago that *"the microbe has come of age. The world of microbes represents as complicated a biological system, with as complex interrelationships, and with as many varied applications as the world of higher animals or plants. There is no field of human endeavor, whether it be in industry or in agriculture, whether it be in the preparation of foodstuffs or the problems of shelter and clothing, whether it be*

in the conservation of human and animal health and the combating of disease, where the microbe does not play an important and often a dominant part."

In speaking before the National Academy of Sciences (*29*), I emphasized that "there is increasing appreciation of the probability that nature harbors many unknown organisms, and that we still have quite incomplete knowledge of the activities, potentialities, and importance of many well-known microbes . . . We are finally approaching a new field of domestication of micro-organisms for combating the microbial enemies of man and his domesticated plants and animals."

Certain soil-inhabiting fungi are potential plant pathogens and are capable of causing immense damage to various higher plants. They may be antagonized, however, by certain soil saprophytes, such as *Trichoderma,* which cause the destruction of the pathogens. The saprophytic fungi, in their turn, are subject to attack by certain actinomycetes and spore-forming bacteria, largely through the production of antibiotic substances. The actinomycetes and the bacteria may also be subject to destruction by certain phages or antibiotics. The chain of events thus becomes so involved that one can hardly recognize where the harmful organisms leave off and the useful ones begin.

One can thus demonstrate in the soil a number of reactions, some of which have already been fully elucidated and can be taken advantage of in modifying certain soil practices. Other reactions are still insufficiently understood. The microbiologist has thus made an important contribution to our understanding of soil processes and to the improvement of plant growth. The task has not been finished, however; new horizons have been opened which await his attention (*25*).

The Actinomycetes and Their Antibiotics

AMONG the major groups of soil-inhabiting micro-organisms, I would like to give special consideration to the actinomycetes—first, because of my own special interest in this group of microbes, and second, because they have recently come to occupy a highly important place as producers of antibiotics.

In 1891 the eminent American botanist, Thaxter, made a detailed study of a soil actinomycete that causes scab of potatoes (*21*). Unfortunately, Thaxter failed to recognize the specific nature of this organism and considered it as a true fungus, which he named *Oospora scabies.* Another American botanist, Halsted, studied about the same time the eradication of potato scab in New Jersey soils (*9*). He found that the severity of infection could be reduced by the application of sulfur to the soil. However, Halsted failed to recognize, on the one hand, the true nature of the scab-producing organism, and, on the other, the fact that it was the acidity resulting from the oxidation of sulfur by specific bacteria that reduced the activity of the scab organism. Halsted wrote that "Sulfur is, all things considered, the best remedy for the scab and soil rot that the experiments suggest." It was recommended that the sulfur be used directly with the seed potatoes or previously mixed with soil and placed in hills prior to setting out the plant. Subsequent experiments demonstrated that "the scab fungus is actively retained in the soil for at least 6 years without the presence of potatoes or beets." [3]

Even the fundamental studies of Beijerinck (*1*) on the role of actinomycetes in the formation and decomposition of humus in the soil failed to receive much attention from bacteriologists and agronomists.

It was only about the middle of the second decade of this century that several investigations were initiated on the occurrence, nature, and activities of actinomycetes in the soil. The work of Fousek in Austria (*8*), of Krainsky in Russia (*11*), of Conn (*3*), and of Waksman and Curtis (*28*), in this country, laid the basis for a comprehensive examination of the nature and activities of soil actinomycetes and their role in soil processes. These were soon followed by the work of Drechsler (*6*) on the morphology of these organisms, by Lieske (*12*) on their physiological properties, and by Ørskov (*16*) on their systematic position and classification. In spite of these studies, however, the universal recognition of these organisms as soil inhabitants was still lacking. This can be shown by the fact that Russell and his associates (*20*) at the Rothamsted Experimental Station in England barely mentioned the actinomycetes in a book entitled

[3] Among the animal diseases caused by actinomycetes, "lumpy jaw" of cattle occupies an important place (*15*).

The Micro-organisms of the Soil published in 1923; they considered them among the Fungi Imperfecti. An attempt was made soon after, however, to correct this oversight by the writer of these lines, who devoted a comprehensive chapter to them, in his book *Principles of Soil Microbiology* (*22*).

It was not, however, until the discovery that actinomycetes have the capacity to inhibit the growth of various microbes—including bacteria and fungi that are responsible for the numerous diseases of man, animals, and plants—that they began to receive detailed consideration. But even now, with numerous laboratories throughout the world devoting much attention to the occurrence of actinomycetes in soils and in composts, their role in natural processes, especially in the soil as it affects plant growth, still remains largely a matter of speculation (*14*).

Formerly believed to comprise one genus to which the name *Actinomyces* has been applied, the actinomycetes have now been separated into a dozen different genera and numerous other generic names are under consideration. The basis for the generic separation of these organisms has been largely morphological, supplemented by certain chemical properties of their cells. The recognition of actinomycete species is based largely upon cultural properties and biochemical activities. Several hundred species are now recognized; hundreds of others are listed in the literature, but have not been universally accepted because of insufficient data for their proper identification.

Among the biochemical activities of the actinomycetes, major attention has been paid to their ability to form antibiotics. More than 500 chemical compounds and preparations, in various stages of purification, have been isolated; many of these have been identified as to their chemical structure. About 50 of these compounds have already found practical application in the treatment of numerous infectious diseases in man, animals, and plants. Some antibiotics are active largely upon bacteria; others only upon fungi, and still others upon both fungi and bacteria; some are active upon protozoa. These antibiotics vary greatly in their physical and chemical properties, toxicity to body cells, range of activity upon different organisms or antibiotic spectra, and mode of action upon sensitive organisms. Many new types of chemical compounds have been discovered as a result of the study of the chemistry of these antibiotics. Some of them have found a place as biochemical tools for the study of various important reactions essential to living processes.

These antibiotics also have a variety of agricultural uses—in the treatment of plant diseases, in the feeding of nonherbivorous animals, and in the preservation of certain foodstuffs, as well as of a variety of other biological materials where they have largely replaced the purely chemical preservatives.

The control of plant diseases by antibiotics has been explained either by their action upon the parasite, or upon the host, or because of certain chemical changes that they undergo within the plant. The rate of absorption of the antibiotic and its transport within the plant is of great importance. It depends on the mode of application, amount used, nature of plant, and environmental conditions.

Among the various antibiotics of actinomycetes, streptomycin has received major consideration. By placing chrysanthemum cuttings in a streptomycin solution, Pramer *et al.* (*17*) found that the plants inoculated with a streptomycin-susceptible strain of *Erwinia chrysanthemi* were protected by the streptomycin treatment; whereas those that were inoculated with a streptomycin-resistant strain were attacked by the pathogen, thus establishing a direct action of the antibiotic on the disease-producing organism.

Streptomycin found an important application in the treatment of the fireblight disease caused by *Erwinia amylovora* in pears and apples and other rosaceous plants. The cultivation of the Bartlett pear had to be practically abandoned in the eastern part of the United States because of this disease. "Severe russeting of the fruit frequently resulted from the application of copper compounds, a standard treatment against the disease. Blossom sprays with streptomycin appeared very promising . . . Streptomycin sprays and dusts are now part of a routine disease control program in the United States and are officially recommended against fireblight on apples, pears, and some ornamental shrubs of the rose family, and against walnut blight." (*4*)

Among the other important antibiotics used in

219-743 O—66——2

the treatment of plant diseases, cycloheximide, tetracyclines, some of the polyenes, and blasticidin S were found to be of primary importance. Cycloheximide is active on numerous fungi and yeasts, but not on bacteria. Unfortunately, its phytotoxicity prevents its use against many plant diseases unless the treated plants are relatively resistant to the antibiotic. When effective in low concentrations, as in the treatment of cherry leaf spot caused by the fungus *Coccomyces hiemalis,* cycloheximide has found a place.

Extensive screening programs for organisms producing antibiotics active against plant pathogens are now being carried out, often with encouraging results, as in the isolation of kentaricidin active against apple scab (*19*). Pridham *et al.* (*18*) reported on the activity of various actinomycetes against phytopathogenic bacteria and fungi (table 1).

The ability of certain soil micro-organisms to inhibit the growth of other micro-organisms through the production of antibiotics has been variously interpreted as serving (a) to control the composition of microbiological populations in soil and in other natural substrates, and (b) as the natural mechanism of control of plant diseases. The inhibition of germination of fungus spores and the hyphal growth in soils has been widely observed and is referred to as "soil mycostasis." This phenomenon was found to be due to certain factors produced by soil inhabiting micro-organisms, which are thermolabile and are destroyed on sterilization of soil. This gave rise to a new term "microbial mycostatasis." (*5*)

Various investigators have argued that the production of antibiotics in soil serves as a biological control of plant diseases, particularly when antibiotics are formed at the site of infection. Brian (*2*) suggested, however, that, although one "can now say with some confidence that some micro-organisms can produce antibiotics in soil in quantities sufficient to account for some observed biological antagonisms, we have yet to show that the two phenomena are connected . . . some antibiotics are naturally occurring substances and . . . they do exert an ecological effect, expressed in various kinds of microbial antagonism."

According to Waksman (*26*): "Under truly

TABLE 1.—*Inhibitory activity of streptomycetes against selected phytopathogenic bacteria and fungi* (*18*)

TEST ORGANISM	NUMBER OF STREPTO-MYCETES TESTED	NUMBER OF STRAINS THAT PRODUCED INHIBITION ZONES WITH INDICATED DIAMETER			
		0 mm	0–10 mm	10–30 mm	30–50 mm
Agrobacterium tumefaciens	482	389	65	23	0
Corynebacterium fascians	479	170	106	173	30
Erwinia carotovora	381	337	32	12	0
Pseudomonas phaseolicola	477	327	59	77	14
Xanthomonas phaseoli	680	490	90	89	11
Cerastostomella ulmi	320	284	14	22	0
Cladosporium herbarum	319	257	31	31	0
Gibberella fujikuroi	66	21	26	19	0
Helminthosporium sp.	23	1	7	15	0
Mucor rammannianus	444	295	24	102	23
Trichoderma viride	320	300	17	3	0
Ustilago zeae	318	283	12	23	0

natural conditions such as prevail in virgin prairie and forest soils, one could scarcely visualize a combination of all the factors essential for the formation or functioning of antibiotics unless the organisms are protected by special environments, as in root systems of higher plants, in insects, or in other forms of animal life." After a detailed analysis of the various factors involved, the conclusion was reached that "while under very special conditions antibiotics may be produced, and may even play a part in repressing the growth of certain microbes, their role in modifying the ecology of the microbial population in the soil is still open to question."

Antibiotics are able to exert a stimulating effect upon animal growth—an effect which can not all be explained by the action of known vitamins. Some of the antibiotics, chiefly penicillin and the tetracyclines, bacitracin and neomycin, have come to occupy an important place in the feeding of poultry, pigs, and young ruminant animals. This practice results in increase in the growth response and food conversion by 5 to 50 percent. The favorable effect upon gastrointestinal infections of animals has often been ascribed to their action. It is particularly evident in inadequate diets, but less in well-assimilated diets. This gave rise to the expression that "antibiotics compensate for poor husbandry."

Antibiotics are also used in the preservation of foodstuffs, including fresh and processed foods. Fish and poultry are usually preserved by immersion in ice, or in a solution, containing the antibiotic. Research is being conducted on the preservation of beef by injecting an antibiotic into the animal immediately prior to slaughter, followed by surface treatment of the carcass. However, this process is not being used commercially, nor has it been approved by the Food and Drug Administration. Nystatin may be applied to the skin of bananas to control spoilage by fungi. Valuable biological products, including virus preparations (poliovirus, poultry vaccines), and human and animal semen can also be preserved by the use of certain antibiotics.

By using microbes as tools for the study of various biochemical reactions, as well as of processes of heredity, man has gained an insight into the mechanism of life never made possible before. The biochemist is making use of antibiotics as specific inhibitors of metabolic reactions: chloramphenicol brings about inhibition of protein synthesis, antimycin inhibits cytochrome oxidase, actinomycins exert an activity upon nucleic acids. The full potentialities of the antibiotics as biochemical agents have not yet been exhausted.

In addition to the production of antibiotics, actinomycetes have found important practical applications through their ability to (a) transform steroids, and (b) form certain vitamins, such as B_{12}, and various enzymes such as certain proteases, diastases, and oxidases.

SOIL MICROBIOLOGY AS A SCIENCE

CERTAIN questions have been raised earlier as to the justification of spending much effort in developing a field of science that has yielded what was previously considered to be limited practical results. This was pointedly expressed in the late thirties by a member of the U.S. Department of Agriculture, who said, "I know of no field of knowledge that has contributed less, for the efforts spent, to practical developments than has soil microbiology." Only 10 years later, however, another eminent leader in agriculture in this country made the following statement:

"If all the agricultural experiment stations of this country had contributed nothing else of practical importance than streptomycin, all the expenditures involved in all the experiment stations throughout their whole existence would have been fully justified."

This particular antibiotic—as well as the numerous others that have found important practical applications—is produced by the actinomycetes, a group of soil micro-organisms. These chemical products have revolutionized medical and veterinary practice and have added untold wealth to our economy (table 2).

One may, therefore, logically raise the question whether the science of soil microbiology has not narrowed down at present to the subject of antibiotics. Although it is now fully recognized that certain groups or strains of microbes found abundantly in the soil have the capacity to inhibit the growth of other microbes, the importance of such processes in the soil itself is still open to question. The fact that certain microbes can inhibit the growth of others does not yet justify any generalization concerning their practical signifi-

cance in modifying the nature of the microbial soil population and its activities. Even more important is the question: Of what significance is this knowledge in an effort to modify agricultural practices? It is true that antibiotics obtained from soil-inhabiting microbes are being used to control many animal and certain plant diseases, not to speak of human diseases. It is also true that some of these antibiotics have found extensive application in animal nutrition, in food preservation, and in certain other processes that have an important bearing upon agricultural economy. *But the revolution in soil management resulting from important discoveries in this field is yet to come.*

On the other side of the ledger, one must emphasize that in spite of this pessimistic attitude towards the practical accomplishments in the field of agriculture that have so far resulted from the work done in soil microbiology, much theoretical and practical information has already been obtained. Perhaps not as much as to justify all our expectations, but a great deal. The problem now is to determine what other aspects or phases of this field of knowledge still remain to be explored.

First of all, there is the problem of quantitative and qualitative composition of the soil microbiological population. This comprises not merely the counting of organisms capable of developing on a particular medium or the listing or naming of large numbers of such organisms. This has been done and can easily be carried out to some extent further. It involves much more than that. It involves a study of the effects of climatic, geological, environmental, and a host of other factors, especially the nature and formation of the soil, upon the microbiological population. This approach might well be designated as the *ecological,* and embraces a study of the relationship of the soil organisms to their environment.

Second, there is the problem of the relation of the composition of the soil microbiological population not only to the above factors but the interrelationships among its constituent members. This aspect might be designated as *population interrelationships,* comprising both associative and antagonistic, symbiotic and antibiotic, particularly in relation to soil processes and plant growth.

A third phase of the population studies must involve the *plant-microbe associations. These are* significant from the point of view not only of the stimulation of plant growth by microbes or the injurious effect of certain microbes, but also of the formation by microbes in soil of a variety of chemical substances that either favor or injure plant growth.

Fourth is the *biochemistry of the soil.* This approach involves much more than the study of chemical activities of microbes found in the soil, much more even than the overall processes occurring in the soil itself; it involves the bearing of these processes on soil transformations and upon plant growth. It is also concerned with a study of the various factors influencing such processes, especially as they affect different systems of soil and crop management.

THE HUSBANDMAN

LONG before man suspected the existence of microbes or living systems not seen with the unaided eye, he learned to take advantage of their activities to increase his food supply, to improve its flavors, and often to preserve it from spoilage and destruction. The nomad depended upon the lactic acid bacteria to preserve his milk and his milk products. The housewife learned to utilize yeasts (leaven) for raising her bread. The farmer recognized at an early stage that a previous growth of legumes upon land resulted in an increase in the yield of subsequent crops of wheat and other cereals. In the retting of hemp and flax, workers noted that a pile covered with mud and saturated with water separated the flax from the pit. In this process, the growth of anaerobic bacteria was favored, leading to the destruction of the pectins and other hemicelluloses binding the textile fibers to the pit. The fermentation of a variety of foodstuffs (cucumbers, cabbage, lettuce, fruit) resulted in their preservation. The hygienic measures preached by the ancient Hebrews led to the isolation of disease carriers and to the destruction of human excreta.

With the recognition of the role of microbes in causing infectious diseases, their importance in fermentation processes, and as agents of numerous reactions that make a soil fertile and bring about the purification of waste products, man has gained a vast amount of knowledge of the natural forces that control his life on this earth. He has now learned to combat the carriers of infection, to improve his own nutrition and that of his flocks, and to utilize

essential fermentation processes for a variety of industrial purposes.

With the advent of the antibiotic era, man has found in some of the saprophytic microbes powerful allies in combatting infectious diseases that attack him and his domesticated animals. Man has also learned to combat many plant diseases not subject to proper control previously. He has succeeded in improving the nutrition of his animals by supplying certain antibiotics to their nutrients. Man has also gained additional means of conserving his foodstuffs never dreamt of before.

Other fields in which microbes may play an important, if not an essential role, appear on the horizon. The potential utilization of microbes, both autotrophic (chlorophyll-containing) and heterotrophic (saprophytic) groups, such as algae, yeasts, and certain molds for food purposes, appears to be within the realm of economic possibility.

The husbandman is thus able to make use of microbes in two distinctly different ways: (1) In the field, where he applies improved methods of soil management by using crop rotations, green manuring, proper application of stable manures and fertilizers, he is able to make his soil more productive, thus improving his own health and that of his flocks. (2) In the laboratory, just as in earlier and more recent times, the soil has been used as a storehouse of nutrients for the growth of crops with the help of invisible and unappreciated microbes; so is the soil used now as a storehouse of microbes for producing antibiotics and other valuable chemical substances. Within a period covering about a quarter of a century, production of antibiotics has reached an annual sum of many hundreds of millions of dollars.

The search for new antibiotics continues throughout the world. It is largely the soil, mother earth, that has yielded the greatest number of organisms found capable of producing chemical substances dubbed by the public mind as "miracle drugs." Thus, it is truly out of the earth that man's salvation has come.

TABLE 2.—*U.S. production and value of antibiotics—1956–1963* (27)

HUMAN AND VETERINARY USE	PRODUCTION *thousands of pounds*					VALUE *thousands of dollars*
	1956	1958	1960	1962	1963	1963
Bacitracin	NA	7	4	5	10	1,275
Neomycin	17	35	30	49	80	4,881
Penicillins	631	516	859	1,289	1,041	43,676
Streptomycin and Dihydrostreptomycin	622	740	997	1,130	[1] 1,642	14,801
Tetracycline	220	287	287	431	424	66,473
Other antibiotics	477	1,027	792	1,061	1,557	199,810
Total	1,967	2,612	2,969	3,965	4,754	330,916
Feed supplements, food preservation, and agricultural uses, all types	779	903	1,199	2,357	2,509	57,196
Total, all uses	2,746	3,515	4,168	6,322	7,263	338,112

[1] Data obtained from sales figures, by applying factor 5/4; some of the data are duplicated.

LITERATURE CITED

(*1*) Beijerinck, M. W.
1900. uber chinonbildung durch streptothrix chromogena und lebensweise dieses mikroben. Centrbl. Bakt. II, 6: 2–12.

(*2*) Brian, P. W.
1957. the ecological significance of antibiotic production. In: Microbial Ecology. VII Symposium Soc. Gen. Microbiol., p. 168–188.

(*3*) Conn, H. J.
1916. a possible function of actinomycetes in soil. J. Bacteriol. 1: 197–207; N.Y. State Agr. Expt. Sta. Tech. Bull. 60.

(*4*) Dekker, J.
1963. antibiotics in the control of plant diseases. Ann. Rev. Microbiol. 17: 243–262.

(*5*) Dobbs, C. G., and Gash, M. J.
1965. microbial and residual mycostatis in soils. Nature 207: 1354–1356.

(*6*) Drechsler, C.
1919. morphology of genus actinomyces. Botan. Gaz. 67: 65–83, 147–164.

(*7*) Dubos, R.
1932. factors affecting the yield of specific enzyme in cultures of the bacillus decomposing the capsular polysaccharide of type III pneumococcus. J. Expt. Med. 55: 377–391.

(*8*) Fousek, A.
1913. uber die rolle der streptotricheen im boden. Mitt. Landw. Lehrkan. K. K. Hochschule f. Bodenk. Wien, 1: 217–244.

(*9*) Halsted, B. D.
1895. field experiments with potatoes. Bull. 112, N.J. Agr. Expt. Sta.

(*10*) Hilgard, E. W.
1912. soils, their formation, properties, composition and relations to climate and plant growth. The Macmillan Co., N.Y.

(*11*) Krainsky, A.
1914. die aktinomyceten und ihre bedeutung in der natur. Centrbl. Bakt. II, 41: 649–688.

(*12*) Lieske, R.
1921. morphologie und biologie der strahlenpilze. Leipzig, G. Borntraeger.

(*13*) Lipman, J. G.
1911. bacteria in relation to country life. The Macmillan Co., N.Y.

(*14*) Millard, W. A., and Taylor, C. B.
1927. antagonism of micro-organisms as the controlling factor in the inhibition of scab by green-manuring. Ann. Appl. Biol. 12: 202–216.

(*15*) Mohler, J. R., and Shahan, M. S.
1937. lumpy jaw, or actinomycosis. U.S. Dept. Agr. Circ. No. 438, p. 1–9.

(*16*) Ørskov, J.
1923. investigations into the morphology of the ray fungi. Leven and Munksgaard. Kobenhavn.

(*17*) Pramer, D., Robison, R. W., and Starkey, R. L.
1956. the mode of action of antibiotics in the control of plant disease. Phytopath. 46: 341–342.

(*18*) Pridham, T. G., Shotwell, O. L., Stodola, F. H., Lindenfelser, L. A., Benedict, R. G., and Jackson, R. W.
1956. antibiotics against plant disease. II. effective agents produced by streptomyces cinnamomeus forma azacoluta f. nov. Phytopath. 46: 575–581.

(*19*) Rhodes, A., Fantes, K. H., Boothroyd, B., McGonagle, M. P., and Crosse, R.
1961. venturicidin: a new antifungal antibiotic of potential use in agriculture. Nature 192: 952–954.

(*20*) Russell, E. J.
1923. the micro-organisms of the soil. Longmans, Green and Co., London.

(*21*) Thaxter, R.
1891. potato scab. 15th Ann. Rpt. Conn. Agr. Expt. Stat., p. 153–160.

(*22*) Waksman, S. A.
1932. principles of soil microbiology. Williams & Wilkins Co., Baltimore, Md. 1st ed. 1927.

(*23*) Waksman, S. A.
1937. associative and antagonistic effects of micro-organisms. I. historical review of antagonistic relationships. Soil Science 43: 51–68.

(*24*) Waksman, S. A.
1943. the microbe as a biological system. J. Bacteriol. 45: 1–10.

(*25*) Waksman, S. A.
1947. the microbiologist looks at the soil. Intern. Congr. Pure & Appl. Chem., London.

(*26*) Waksman, S. A.
1961. the role of antibiotics in nature. Persp. Biol. Med. 4: 271–287.

(*27*) Waksman, S. A.
1965. a quarter-century of the antibiotic era. In Antimicrobial Agents & Chemotherapy. Proc. Fifth Intersci. Conf.

(*28*) Waksman, S. A., and Curtis, R. E.
1916. the actinomyces of the soil. Soil Sci. 1: 99–134.

(*29*) Waksman, S. A., and Woodruff, H. B.
1940. the soil as a source of micro-organisms antagonistic to disease-producing bacteria. J. Bacteriol. 40: 581–600.

(*30*) Winogradsky, S. N.
1949. microbiologie du sol: problemes et methodes. Masson et Cie, Paris.

Water Development and the Agricultural Sciences

ERNEST T. SMERDON

TREMENDOUS emphasis has recently been placed on water resource problems in the United States. The almost continuous water shortage in the arid West and Southwest poses an endless problem for water development planners. More recently, the prolonged drought in the Northeast—in some respects more dramatic than others—affords ample reason for an immediate and sometimes emotional concern. Providing water to these drought-affected areas stimulates much talk and publicity that sometimes lack the degree of rationality essential in long-range water development planning. Plans to provide water may be loaded with side-effects which are unpredictable, at least without thorough research.

Although discussions on how to solve water problems are always desirable, they generally present only part of the problem. Possible solutions to water problems are suggested, but these suggestions frequently do not adequately consider the total costs; or they ignore other avenues which might be more reasonable in the long run.

In order for long-range planning to be effective in eliminating or minimizing water shortage, all

methods should be fully investigated and appropriate combinations of feasible methods should be incorporated in the water plan. Stated another way, we must not assume that singular approaches such as desalination of seawater or increasing precipitation by weather modification can provide the answer—at least not alone.

The public may come to identify a solution to our water problems with some miraculous scientific breakthrough that will make water available in any quantity desired at a cost which does not seem high. Most breakthroughs, however, are not so dramatic; in fact, they usually consist of numerous smaller developments resulting from the tireless efforts of many scientists. Future contributions by agricultural scientists will probably be in this latter category. But they can be of utmost significance.

WATER DEVELOPMENT PLANS

SINCE water development plans are essential, most States now have them or recognize the need to prepare them. Most plans are quite long range and extend well beyond that period in which we can confidently predict what research breakthroughs may occur. Therefore, the plans are of necessity based on past water uses and supplies from which projections are made. Conservative judgment usually prevails, but decisions which seem conservative when made may be proven otherwise at some future time.

Assume that a shortage of water does presently exist or is anticipated for the region encompassed by a given planning unit—possibly a State or a river basin. This shortage can be caused by inadequate supply or by poor quality of available water, or—more likely—a combination of the two. It can be solved by either of two alternatives: (a) Increasing the supply of water available to the area being considered, or (b) better management of the water already available. Both plans encompass areas where agricultural researchers and life scientists together might make very significant contributions in the future.

Increasing Water Supply

THE total water supply available to a region can be increased only by finding new sources of water. New sources might include water from the sea and water from the atmosphere. These methods involve desalination and weather modification. A third method to increase water to a given area is by interbasin transfer. This latter procedure does not increase total water supply, but imports water from an area of surplus to an area of need.

Desalination.—Desalination of seawater or brackish water is feasible from an engineering and scientific point of view, but whether vast quantities will ever be realized from this source depends on the economics. Data from the First International Symposium on Water Desalination held in Washington, D.C., in 1965 indicate the costs of desalted water to be quite high (*7*)[1]. Depending on the process and size of the plant, present costs range from a low of about 55 cents to over $3 per thousand gallons.

Future costs of fresh water from the sea are estimated at no lower than about 25 cents per thousand gallons, but two factors remain crucial. First, the large nuclear dual purpose plants which desalt water and generate electricity will require a simultaneous continuous market for both water and electricity. Also, the large-scale plants being projected are up to 100 times larger than any with which we now have experience; therefore many scientific and engineering problems will need to be solved. The second factor concerns the problem of fixed costs and water transportation cost which may be a sizable part of the cost of desalted water. These costs are not as frequently mentioned in costs of desalted water as are energy costs.

Weather Modification.—In 1964, a National Academy of Sciences panel released a report entitled "Scientific Problems of Weather Modification" (*6*). This report dampened expectations of getting a major triumph in modifying the weather and increasing precipitation very soon. Many past studies on the effect of cloud seeding have been difficult to evaluate because of shortness of records and problems of getting statistical control. Moreover, cloud seeding often appears to decrease precipitation.

Although our understanding of the precipitation process is increasing, much remains to be learned. It has not been demonstrated yet that precipitation from winter orographic storms (those originating in mountains) can be significantly in-

[1] Italic numbers in parentheses refer to Literature Cited, p. 20.

creased by seeding, nor that hurricanes can be steered or diminished by seeding, nor that black dust or other surface treatments increase precipitation (*10*). Actually, the time scale for success in increasing precipitation by weather modification needs to be measured in decades, not years.

More recent reports on weather modification by the National Academy of Sciences panel and a Commission on Weather Modification established by the National Science Foundation indicate a somewhat more optimistic view toward increased precipitation through weather modification (*1*). Both these groups emphasize the need for more research in weather modification. It is quite likely that expenditures for research in weather modification will increase significantly as a result of developing interest (*2*).

Interbasin Diversion.—When sufficient waters do not exist in a river basin or other planning unit to meet the projected needs, transfers from regions of surplus are often proposed. This method of solving the water problems has much in its favor. The water does exist in a usable form and the engineering technology usually exists to make the transfer feasible, provided the economics justify the project. Quite often the transfers can be made for only a fraction of the cost of providing water by other means such as desalination. Yet, many problems stand to hinder future transfers.

The transfer may cross jurisdictional boundaries and political problems may exist between the basin of origin and the point of use. Also, people living in the basin may consider their apparent surplus water as a resource that will be needed for the future development of that region. Yet, sound deliberations concerning the political and social decisions must prevail and, hopefully, decisions which justly consider all interests will be rendered.

But there are factors which should be considered in transfers of water from one basin to another—regardless of whether the basins are adjacent or half a continent apart, and these factors need research. This research should provide the data so that rational decisions can be made and side-effects which might have been unanticipated can be predicted and avoided.

Costs of large scale transfers will be high and analyses of alternative procedures should be thoroughly evaluated. These procedures include conserving and more effectively using and reusing the present water supplies of the basin—concepts that will be discussed more fully in a subsequent section.

Large-scale interbasin transfer projects may establish conditions that are irreversible. They will inundate vast areas. The regimen and biota of streams may be changed in unknown ways. Natural rejuvenation of stream quality may be changed either for better or worse. The ground water regimen of the basins of origin and use as well as intervening basins may be affected. Also, coastal regions at the outlet of streams of origin may be changed to the extent of creating a completely altered environment in the bay and estuarial areas. These changes can affect fish life because the breeding and nursery grounds of certain species may be irrevocably altered.

In general, answers to the questions posed are not known. But they must be researched because transfer of water will become more prevalent in the future. Each proposed transfer will excite many interested groups on both sides of each question. Hopefully, research on these problems will have been sufficiently farsighted in its planning to solve most of the problems necessary for planners' decisions.

219-743 O—66——3

Conserving Present Water Supply

WATER that falls as precipitation on a basin is subject to being conserved and used until it is (a) lost by evaporation, (b) flows to the sea, or (c) is contaminated with pollutants. This water may be held on the basin for future use by surface structures to store runoff or by procedures which enhance storage in the soil and percolation to ground water aquifers.

The possibility of conserving and using surface waters is generally considered in the early stages of developing a water plan. In most cases, utilization of the dependable surface flow to meet the needs of an area will be thoroughly studied before importing water from another basin, or before other expensive alternatives are proposed. Certainly, prudent planning dictates that readily available waters within the basin be conserved and utilized before advocating more complex alternatives.

Consider what might be done to increase water supplies by better control of evaporative losses. Some examples will illustrate the magnitude of this loss.

The average water budget of the United States excluding Alaska and Hawaii shows that 5 billion acre-feet of water falls as precipitation each year (*8*). Over 3.5 billion acre-feet of this water is evaporated or transpired near the area where it falls. This evaporation amounts to over 10 times the water which is presently used in the United States. Perhaps half of this water is lost by transpiration and therefore contributes to plant growth. Yet, much of this transpiration loss can be attributed to water use by such noneconomic plants as weeds, brush, and phreatophytes. These growing plants may have value only from esthetic, wildlife habitat, and soil protection considerations. Although the importance of these values should not be minimized, part of this water loss might be reduced and man could still retain the indirect value of these growing plants.

Texas can be used to illustrate what this loss can mean. The State receives an average annual precipitation of 27 inches compared to 30 inches for the United States (*4*). Yet, the average annual water budget of Texas is similar to that of the Nation as a whole. Nearly 40 percent of the water that falls on Texas is lost through evaporation. The overwhelming majority of this

loss, which does not include transpiration, is evaporation from the soil surface and plant surfaces immediately after a rain. This amount alone is more than three times as much water as flows into the sea from Texas. In addition, nearly 46 percent of the incoming water is lost by transpiration. Over 80 percent of this transpiration loss is from noneconomic plants. Water losses from evaporation—including that from lake and stream surfaces—amount to 148 million acre-feet per year. Transpiration losses from noneconomic plants total 138 million acre-feet per year. Both of these losses, which are evaporative, are gigantic; together they amount to nearly seven times the total stream discharge into the sea. If research can find ways to reduce these losses, the impact would be gratifying.

Consider that it might be possible through research to reduce losses from evaporation and noneconomic crop transpiration by only 5 percent. The water saved would be 14.3 million acre-feet per year or one-third as great as the total discharge into the sea. Let's postulate that this water saved enters ground storage to be pumped or to provide stabilized seepage flow to streams. This water would provide the needs of 7.6 million people at the 1964 per-capita use rate of 1,675 gallons per day (*3*). This use rate includes all uses of water and is not to be confused with per capita municipal water use rates which are about a tenth as large.

Consider what this 14.3 million acre-feet of water per year would cost if it were obtained by desalination. At 30 cents per thousand gallons, the cost would be $1.4 billion. Although some assumptions have been made in this example, the opportunity for water savings through control of evaporative water losses still is enormous.

The situation for the Nation is essentially the same. Research personnel trained in any aspect of science or engineering, where the fundamentals of soil-plant-water relationships are involved, have a challenging future.

Stream pollution is preventing the effective use and reuse of water in many basins. In industrial areas, waste discharge into streams often exceeds the assimilation capacity of the streams. Waste treatment procedures must be improved to handle not only our present wastes but also more complex ones that may develop in the future. Much additional research will be required on water quality problems. The chances for success are good because of advances in waste treatment techniques which are scientifically feasible in the foreseeable future.

Again the question of economics enters the picture. Can we afford to pollute the water we have and then advocate alternate means to replace this water? When all costs are considered, pollution is a costly process to the public. More rigid controls will probably be legislated if present regulations and self control do not prove adequate.

THE STAKE OF AGRICULTURE IN WATER PLANS

NEARLY half of the water used in the United States is for irrigation (*5*). Furthermore, a large percentage of the water withdrawn from streams and from the ground for irrigation is consumptively used. Legal water use priorities often place irrigation low compared with industrial and municipal uses. Therefore, the large water use for irrigation may sometimes be criticized when water supplies seem inadequate. But the need to provide additional water for irrigation in any proposed water plan may have to be defended, because agriculture's stake in water plans is tremendously important and cannot be regarded lightly.

Importance of Irrigation

IN much of the western part of the United States, irrigation is vital to the well-being of agriculture. It provides insurance in many other areas, particularly for selected crops. As an example of the economic importance of irrigation, one-third of the crops grown in Texas in 1964 was grown on irrigated land (*9*). Yet, two-thirds of the value of harvested crops came from the irrigated production. But the benefit to the economy does not end there, because irrigated agriculture requires more inputs into the production. As a result, the economic benefit to those segments of the economy that support and prosper from agriculture are much greater from irrigated production.

Water plans are developed to provide assurance that the growth and prosperity of an area are not limited by lack of water. If irrigation water is to be provided in the water planning, it is essential that the total impact of irrigated agriculture be recognized and considered.

There is also the question of future needs for food and fiber, both in the United States and the world. There is no certain way of foretelling what the future needs for agricultural production will be. But if the world situation worsened so that more of our agricultural productive capacity was needed, increased irrigation would be essential. Another factor in relation to irrigation which may be overlooked concerns the overall magnitude of U.S. food and fiber production. Many of the irrigated crops such as fruits and vegetables are not in excess supply at the present. Irrigation is necessary to the production of many of these essential crops.

Water Conservation Research Needs

EARLIER it was stressed that most of the water that falls on land surface evaporates directly or is transpired back to the atmosphere. This process accounts for the vast majority of our water losses. Research on evaporation suppression and transpiration is vital and was listed high among the water resources research needs recently given by the National Research Council of the National Academy of Sciences (*11*).

Although evaporation suppression from soil surface and transpiration control are complex, creative research on these problems will undoubtedly make progress. Efforts of plant geneticists, soil physicists, agricultural engineers, and other agricultural researchers should be focused on this type of study. Success may be slow in coming, but when the costs of such research are compared with the potential benefits, a concerted effort is justified. Research of this type should be placed in the perspective of a long-range effort in the same manner as are long-range water plans. Water problems will be continual, and research progress on evaporation suppression and transpiration control will bring endless benefit.

A secondary benefit from any research which controls the water on the soil is the control of erosion and its counterpart sedimentation. Aside from the long-recognized damage of erosion to land is the equally important problem of the ultimate deposition of eroded sediments. As more streams are controlled by reservoirs, the sedimentation of these reservoirs will cause costly loss of storage capacity and shorten reservoir life. It is time that erosion was discussed more as a source of pollution. Research to reduce this pollution is imperative.

A majority of the water, as it goes through the hydrologic cycle, comes in contact with soils and plants after falling as rain. Exceptions, of course, are rain falling on the oceans and rain falling on interior lakes and streams or on man-made surfaces such as cities. Rain on the oceans is not of concern here and rain on interior water surfaces and cities accounts for only a small fraction of the total.

Therefore, the water from which this Nation's water resources must be developed undergoes the interacting forces of nature in the soil-plant environment. More research should be directed to an understanding of those interacting forces so that some day we can economically control them for the good of our water supplies. This research should be done by those who are most competent to study these factors. The historical success of agricultural researchers in related fields places them in good stead to undertake water research problems.

LITERATURE CITED

(*1*) CARTER, LUTHER J.
1966. WEATHER MODIFICATION: PANELS WANT GREATER FEDERAL EFFORT. Science. 151: 428–431.

(*2*) CARTER, LUTHER J.
1966. WEATHER MODIFICATION. Science. 151: 804–808.

(*3*) GEOLOGICAL SURVEY RESEARCH
1964. WATER RESOURCES. Chapter A, U.S. Geological Survey Professional Paper 501A. A19–A20.

(*4*) JOHNSON, J. R.
1957. THE SIGNIFICANCE OF A WATER BUDGET FOR TEXAS. Proceedings, Third Annual Water for Texas Conference. College Station, Tex. Texas A & M University.

(*5*) LEOPOLD, LUNA B., AND LANGBEIN, WALTER B.
1960. A PRIMER ON WATER. U.S. Dept. of the Interior, Geological Survey.

(*6*) NATIONAL ACADEMY OF SCIENCES
1964. SCIENTIFIC PROBLEMS OF WEATHER MODIFICATION. Pub. 1236, National Academy of Sciences-National Research Council. Washington, D.C.

(7) Resources for the future
1966. resources: some findings and conjectures from recent research into resource development and use. No. 21, Washington, D.C., Resources for the Future, Inc.
(8) Revelle, Roger
1963. water resources research in the federal government. Science. 142: 1027–1033.
(9) Runkles, J. R., and Smerdon, E. T. (ed.)
1965. agricultural resources related to water development in texas. Prelim. Rpt. to the Texas Water Dev. Board. College Station, Tex., Water Resources Inst., Texas A & M University.
(10) Walsh, John
1965. weather modification: nas panel report. Science. 147: 274–276.
(11) Wolman, Abel
1962. water resources—a report to the committee on natural resources. National Academy of Sciences, Pub. 1000B, Washington, D.C.

Spent Chickens - A Source of Mink Feed

In the early days of mink ranching, horse meat was one of the basic ingredients of mink rations and supplied most of the fresh meat in the diet. During recent years, however, the high cost and scarcity of horse meat has forced mink ranchers to seek more economical sources of fresh meat for their animals.

A study was conducted at the Michigan Agricultural Experiment Station to investigate a method of processing "spent" chickens for mink feed. "Spent" chickens are birds 18 to 20 months old which are no longer profitable for egg production and are not in demand as food for human consumption. This poultry product was used as a substitute for the more costly ingredients of rations during late growth and furring of mink.

The "spent" chickens were treated with the antibiotic, neomycin, in their drinking water then killed, scalded, defeathered and frozen; they were not bled or eviscerated. The frozen birds were ground and fed to mink at 0, 12.5, 25 and 50 percent levels.

Rate of growth of mink increased as the level of poultry product became greater. Fur quality of the mink was not adversely affected by the feeding of the "spent" chicken but the incidence of "wet belly" was greater with diets high in poultry, probably due to the high level of fat. No other hormonal disorders or diseases attributable to the feeding of chickens were encountered.

From: Quarterly Bulletin, Vol. 47, No. 3, 1965
Michigan Agricultural Experiment Station

AGRICULTURAL RESEARCH
A Key to Understanding Our Environment

DANIEL G. ALDRICH, JR.

On February 23–25, 1966, the U.S. Department of Agriculture and the National Academy of Sciences jointly sponsored a symposium on agricultural research at Airlie House, Warrenton, Va. Purposes of the symposium were: (1) To consider needs and opportunities in agricultural research, (2) to examine the relation of agricultural research to the missions of agriculture, (3) to consider the integration of agricultural research with the main body of science in the universities, with industry, and among executive agencies, and (4) to consider the role of the United States in agricultural research in developing nations.

From the wealth of materials presented at this symposium and from the spirited discussions among the participants, a number of critical issues came sharply into focus. To give readers a sampling of the kind of thinking this symposium engendered, *Review* presents in this issue condensations of four randomly selected papers. The articles appear on pp. 22 through 39.

IT has become reality to talk about a world of 3 billion people. It seems appropriate then to give some thought to an accompanying reality—not just the distribution of calories around a crowded world, but the total impact of people on the land, the air, the sea, and all other resources of our environment.

We can guess that a few hundred millenia ago, man left his environment pretty much alone. If we don't want to go as far as to say the environment created man, we can surely say that he held his own as a species because he was an adaptable organism. He could live in the environment he found.

We've come some distance from that beginning. It is one of our definitions of man that he is distinguished among the species by his ability to modify his environment.

In this century, of course, that ability has become all too obvious. In some cases man has modified his environment within an inch of its existence—and his own.

Man, A Modifier of Nature

OUR cities made of freeways, parking lots, and a hundred miles of subdivisions are massive modifications of the land and nature. So are our great buildings and bridges, our parks, our cultural life, and our universities themselves. But these monuments to our capacity to modify the world are themselves results of man's ability to select seeds to grow and animals to feed and milk, of his ability to move water to plants, and to nourish them with fertilizers. They are results of all man's inventions that have given him more food, clothing, and shelter, and have let him multiply.

The basic modifier of nature is agriculture. And behind change there must always be experiment.

The first cliff dweller who saved seeds from his biggest head of grain for next year's planting was a straight-line progenitor of today's geneticist—an agricultural researcher. Today's seed selection may be a little more sophisticated. The researcher understands genetic principles and he may choke the computer with a lengthy formula. But the object is the same.

The brother of our cliff dweller who found he could eat all winter if he saved his seeds in a cool dry place—he was an agricultural researcher too. Today, agricultural scientists are searching more than ever for ways to save the foods we grow for future use. The research tool may be an 11-foot pit, lined with heavy concrete and lead. At the bottom, under water, is a dangerous object—cobalt—that gives off gamma rays. Only a flat of strawberries being lowered into the pit for exposure to the rays tells us this is agriculture. But its objective is the same—finding means of keeping perishable foods longer.

An engineer may turn his experiments toward fundamental laws of inertia. But from his knowledge may come a machine that will shake a prune tree just enough to drop the fruit into a catching frame and not enough to hurt the tree. The fundamental study of a physical principle may also be agricultural research.

We may find a forester driving 5-foot tubes into the earth around a 2,000-year old redwood tree. He lowers a neutron emitting device to the bottom of the tube. Instruments then count reflections from hydrogen atoms in the water molecules stored in the soil. Here, nuclear science measures the moisture supply of *Sequoia gigantea* and gives us new knowledge of an ancient part of our environment—a forest that was mature centuries before the Christian era. The nuclear device in the tube in the forest is an agricultural research tool.

We may see a crew of workmen building a concrete dam across a dry streambed. Above the dam, brush and excess trees are cut or killed with chemicals, the watershed is burned, and the land is planted to grass and clover. With the dam, scientists can measure the flow of a creek that is no longer dry. They learn how much water brush and trees transpire. Fire, the ax, and a dam on a dry creek are tools of agricultural research.

We may find a scientist and a technician piling grass or brush under a metal structure that looks like a giant Indian teepee. Then they set the pile on fire. This is agricultural research, too. Instruments at the top of the teepee measure gases given off by burning grass, straw, and different species of brush. As a result, the contribution of agricultural burning to atmospheric haze and smog becomes a scientific fact rather than an accusation.

In another laboratory we find a researcher carefully measuring drops of a solution into a tank of very small fish. The scientist uses them as a biological measure of chemical toxicity in an almost unmeasurable amount. The fish, too, are research tools of agriculture.

In a white-tiled laboratory the nearest thing to nature may be chlorophyll in a glass tube. The scientist is concerned with the flow of electrons in the steps of photosynthesis. But this is agricultural research. It yields information on life's processes for deposit in the bank of basic knowledge. Agriculture's increasingly sophisticated problems can be solved sooner because this bank of research knowledge exists.

Agricultural research has indeed become a sophisticated enterprise. Its gamma ray food preservation, its neutrons in the forest, its delving into the functions of chlorophyll and DNA—these are as

"far out" as the advances of other sciences toward understanding of the mind or the moon.

The Research Mission

BUT problem solving has not been forgotten by those who set the course of agricultural research. Problems may be more complex. But complex methods of problem solving match them. And researchers in agriculture are leaders more often than followers in science. Other segments of the universities are only now coming to grips with a problem-solving dilemma that was met by agriculture decades ago.

The modern research device in our universities is the research institute. But the agricultural experiment station, which has been around so long it is taken for granted, is exactly such an institute—a problem-solving agency created to fulfill a special research mission of the university.

That mission might be summed up as a threefold one:

First, to exploit scientific discovery from any and all sources that can be applied to problems of agriculture, technical and practical.

Second, to undertake direct problem solving for agricultural industry.

And third, to engage in basic research in areas where technical advancement of agriculture is most likely to be limited for lack of basic knowledge.

It's not hard to see, of course, that these research interests may pull in opposite directions. Search for basic knowledge demands specialization. And the larger and more complex the university becomes, the more specialized its fields of research are. While the most progress can come where there is high specialization, problems come with it too.

The forces of specialization are highly centrifugal forces. They tend to throw the university apart. They separate a researcher from his colleagues. The trend is strong in a large, science-oriented university such as California. There has to be some integrating force.

With just that aim, many American universities are now creating institutes or centers. In these they can reassemble the specialized scientists into problem-solving groups.

Our Water Resources Center in California is a typical one. This is a universitywide agency. It cuts across lines of departments, colleges, and campuses. Water is obviously a key interest of agriculture and agricultural research in the West, and the director of the center was drawn from our Department of Irrigation. But attached to the center through mutual research interests we have engineers concerned with conversion of seawater, hydraulics engineers, and sanitary engineers, agricultural and nonagricultural economists, marine resources researchers, and representatives of other disciplines.

The universitywide center follows a pattern of organization pioneered in the college of agriculture departments of any land-grant university. A department of animal husbandry, agronomy, or vegetable crops, for example, is an assemblage of highly trained experts—geneticists, physiologists, nutritionists, and biochemists—into a problem-solving team. The agricultural experiment station is itself a larger problem-solving team.

A look at projects on the books today in any State suggests a scope of problems beyond the dreams of those who devised the agricultural experiment station. Today, I believe we can say that agriculture's problems and the research that aims to solve them spread over the whole span of man's involvement with the world he lives in.

Some hints of this show in the colleges' recent reappraisal of their names. Michigan now has a college of agriculture and natural resources. Rutgers, too, is broadening its name and will have a college of agriculture and environmental sciences. Texas is adding a school of natural bioscience to include departments of range science, wildlife science, and parks and recreation.

The outreach of agricultural interest has long passed the old lines of production and marketing to areas that were remote from agriculture a generation ago.

The Pressure of People

AGRICULTURE and its involvement with the pressures of people on the world's resources simply cannot be separated. This involvement will grow because the pressure of people is surely growing. Secretary Freeman noted in one of his recent talks that, even in the United States, this pressure is growing at the rate of five persons a minute. In a year that rate means 2,600,000 more persons competing for parking space and lanes on the free-

ways—competing for class 1 farmland to build houses and garages, shopping centers, and factories—competing for elbowroom by the fishing stream, and for a trailer stall in the national park.

People are already competing for water to drink and bathe in. Even in this well endowed country, people could compete for food, but for the phenomenal success of agricultural research.

The agricultural abundance that makes a hungry future look so remote in the United States has been almost an embarrassment. But it is continuing evidence that the science of agriculture is the science of conservation.

The technology of agricultural abundance has freed men's hands and their inventive enterprise. Conserved energies have created our automobile industry and its roads, our dams and electric power, the electronics industries and their refinements of living, even the air conditioning that has made summers more livable.

Especially, abundance has freed the time of people to enjoy living and to concern themselves with nature and preserving nature. We find nationwide interest now in all of our resources—our mountains and forests, our streams and lakes, and even occasionally our farmlands. These all are our concern largely because agricultural research in this country has solved the problem of feeding and clothing people.

But even in solving an agricultural problem, the research may have marked influence on our total environment.

For instance—consider our rangeland specialist measuring the flow off a watershed he has converted from brush to grass and clover. He may think of livestock, water, or irrigation of the farmland below. But when he has converted worthless, impenetrable brush to grass, he has created a resource for deer and birds as well as cattle. He has opened up new space where urban people can hike and hunt. He has conserved water to fill streams and lakes, where fish can live and be caught. And he has brought open beauty to the landscape. Agricultural research that has taught people how to improve wild lands has paid repeated dividends in conserving natural resources for the public.

The agricultural engineer's basic studies of physics may lead to a machine that will harvest tomatoes, or lettuce, or olives. But there is a social and economic contribution, reaching to people well outside of production farming. The machine may save an industry that might not survive labor scarcity. It conserves manpower and also human dignity by making better jobs—jobs that call for higher skill and higher pay. A new farm machine creates jobs for the men who build it, too, and the economic lift of new wealth in a community.

The inventiveness of the agricultural research worker is translated into benefits for people who may themselves see no connection with agriculture.

Research scientists irradiating a crate of strawberries may be running one of agriculture's far-out experiments. But they may, in this or other research, find the key to long shelf-life of fruits and vegetables harvested at their peaks of ripeness. This is resource conservation in one of its highest uses, research to preserve the product of the soil from waste and bring it to the table at the highest point of quality.

An agricultural scientist seeking out the components of smog, or measuring toxicity of a new chemical in parts per billion, concerns himself first with agriculture. Smog plays havoc with the tender leaves of vegetables and other products of the farm. It has been an incidental benefit too to know that agricultural burning is itself a very minor smog maker. Finding what chemical residues, in the most minute amounts, may do to living organisms is of first interest to agricultural users of chemicals.

But the atmosphere and soils and water are some

of the most obvious components of our public domain. There is no one without a stake in agricultural research that concerns itself with pollution of any kind—by waste gases, liquids or solids, by any of the inevitable byproducts of modern living.

Direction Signs for the Future

I BELIEVE the direction signs for the future in agricultural science are clearly posted. The soils, the water, the atmosphere, and all that grows in this environment—cultivated or in nature—are inseparately involved with agriculture in its narrow sense and with agriculture as the environmental science.

Our national and international policies demand that we harness science to economic and social development. We see national commitment not only to goals of better distribution of wealth and income but to more beautiful surroundings. It is our national intent that the environment we live in should do more for people than feed, clothe, and house them.

In the last annual report of "Resources for the Future," that organization's President, Joseph L. Fisher, expressed some thoughts that are certainly pertinent here. He said:

"We are entering a period in which people generally will be deeply concerned with how natural resources and the natural environment are used. Merely getting enough cheap food and materials will not be enough; people will want to be sure that the quality standards are established and enforced in terms of water and air purity, landscape protection, and the physical and psychological health of human beings. The public interest clearly must embrace quality as well as quantity in the matter of natural resources."

Obviously, the problem we're talking about is not a great deficiency in production research—the kind that will bring us a better carrot or more carrots, or even the sophisticated development of machines that will harvest grapes or strawberries. In the larger area of agricultural research embracing the total natural resource, the essence of our need may be in the economic and social sciences rather than in the more familiar natural sciences and technology.

But if the historic emphasis of agricultural research is shifting or expanding, what about the clientele? Is the agricultural scientist talking to the same people who listened to him when he confined his attention to new hybrid seeds, new water uses, new fertilizers, and other aspects of research to make crops grow and grow better?

I think not. At least agriculture should be talking also to a new clientele as research turns to problems that call for the expertise of social and political scientists.

In farm production, processing, and marketing, there has always been a ready clientele or public to work with and for the testing and developing of research ideas. Engineering research and development has always had its clientele in industry. Medical science in the university laboratories and hospitals has its responsive client in the medical community.

But when it comes to applying research in the social and political sciences, there is no ready bridge to the clientele. Our new clientele, in fact, may well be the whole world. So, our ability to apply what we already know to the problems of total resource development is exceedingly limited.

Concerted Action

SOME directions of research and action on the problems of our environment almost point themselves out. We hardly need look to find one near at hand, where the Potomac estuary carries off the wastes of 3 million people and their industries. Sanitary engineers have raised the level of waste treatment, but increasing population has offset the improvements.

We are too prone to count on natural dilution to solve our problems. The Potomac estuary has been overwhelmed by the volume it has been asked to dilute, just as the air over Los Angeles has been unequal to the burden of hydrocarbons poured into it from automobiles. And if metropolitan Washington has a problem, so has California's high Sierra. Six thousand feet up in the Sierra, the blue that made Lake Tahoe famous is threatening to turn to an algae green as the wastes pour in.

We can look beyond the land itself and find a ready problem of conserving and developing the world's natural resources. The oceans are no longer something apart. Marine resource scientists can find DDT and its metabolites in fish and shell fish over half the Pacific—in samples taken from Seattle to the Gallapagos and from San Francisco to

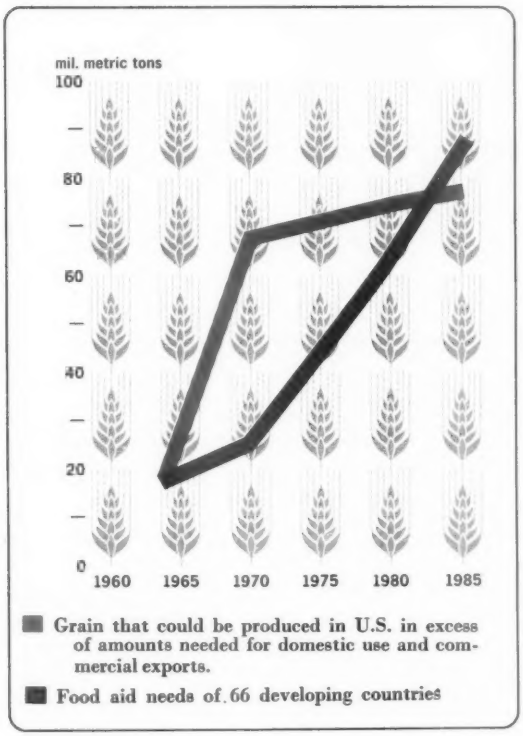
Hawaii. It is clear that pollution of water as well as air poses an international drift problem. Chemically, at least, we have become one world.

It's no solution to say, "Limit the people." Or, "It's too late." The problem is here now. We know, or are well on the way to knowing, techniques that can solve a lot of the problems of water pollution, air pollution, and resource conservation and use. But still we fall short in learning how to organize people to be problem solvers.

I am not discouraged about our eventual progress, just as I am not ready to concede the hungry future we hear described so often.

As recently in our history as the early 1930's, a few scientists who worried about this country's loss of topsoil were simply voices crying in a wilderness of disinterest. Farmers were barely aware of their own problem. If they were, they knew little that they could do about it. City people cared less.

U.S. AVAILABILITY OF ALL GRAIN FOR FOOD AID AND FOOD AID NEEDS OF 66 DEVELOPING NATIONS, 1970–1985



Today, across an increasingly urban country, soil conservation is almost a social movement.

I think agricultural research is well tooled up. With our bank of past research and a coming flood of new knowledge in the biological sciences, our working material is not a problem. Our systems experts with their computers can give public and private administrators technically sound and economically feasible choices for handling a problem such as a river or a watershed. We can project the extent of resources and the population pressures on them into another century.

I am convinced that agricultural research, which has responded successfully through all of its history to the needs of people, must find the means to meet their broader needs today.

The pressure on land and the total of our national resources is intense and growing. The agricultural problem-solving philosophy that brought overwhelming abundance is capable of the same success in new directions.

If agriculture is going to solve the problems that are paramount ones in today's world—at home and abroad—agricultural research must, I believe, apply its historic energy and inventiveness to the social and political sciences.

Research in these fields will produce more insight into how the public interest in planning and developing the environment can be determined, and hence find deeper understanding of which policies and which programs can be the vehicles for carrying forward the public interest.

In summary, agriculture can and must find ways to meet the challenge of resource development in a manner that will fit the needs of our rapidly urbanizing society. The development of our Nation's resources has many economic and sociological problems. It also offers opportunities to both rural and urban peoples.

Agriculture must provide the leadership necessary to create an awareness of the basic problems of our environment. It must provide factual information on which wise decisions can be based, and it must stimulate interest and participation by citizens in developing and implementing a positive resource development program. Such a program must be consistent not only with our overall national goals, but also with the goal and welfare of the agricultural enterprise.

The Agrarian Tradition and the New Science

DON K. PRICE

IN the atmosphere of the 1930's it was very easy to feel that American society had fundamentally gotten off the track a century before—that the strength of the great industrial corporations had come to dominate our politics more than it had any right to do. The world of agriculture seemed to still represent the early Jeffersonian dream.

Here was a separate part of society with its own civil service, so to speak, and its own educational system, each feeding on and contributing to the other. It constituted what was clearly the one administrative service based on the most thorough appreciation of the idea that Jefferson thoroughly understood—that only by a command of the sciences could government and politics and administration reach their complete fulfillment in freedom.

Even as late as the midforties, agriculture had about 47 percent of the Federal research budget, and it was the only one which really had a feel for science as an intrinsic part of its political and administrative system. The Agriculture Department seemed to me the very flower of its type among administrative services throughout the world.

This article was condensed from the transcript of an informal talk not originally intended for publication.

Post-War Science

AS other agencies turned toward the planning of postwar science, their main fear was the same one that had stopped Federal support of science during the 1930's—the fear that there was no way in which the Federal Government could support the sciences without destroying the freedom of science. Of course the record of the Agriculture Department was absolutely clear on this. We called it cooperative federalism then and thought we had invented a fancy new term. It is creative federalism today—the notion that it is not necessary in a great national system to destroy freedom and variety simply because that system has to be financed from a central source. Here was something that, it seemed to me, the nuclear physicists from the metropolitan institutions did not then understand. They did not have the benefit of nearly a century of agricultural research to contradict their presuppositions and their prejudices.

When I put that term "agrarian tradition" in the title of this talk, I did not mean it in a derogatory sense. I did it partly because I was something of an amateur historian as a student, and the Jeffersonian tradition seemed to me to embody the heart of the American notion of politics. Also, because I came from the Appalachian backwoods, I really did not think of the agrarian notion about politics as something to sneer at.

Of course it is easy to make fun of oversimplified Jeffersonianism—the superior moral virtue of the farmer, the iniquity of the city dweller. In an age of urban America, this is likely to look a little bit silly. Yet I was positively delighted to hear Secretary Freeman express some regret about the way people are "bottling themselves up in big cities." This represents in some sense a kind of popular agrarianism which has lasted throughout our history—a combination of a regard for the quality of living as against the notion of merely making a living or making money. And in an industrial and technological society, the notion that we might restore the dream of a political system in which the agrarian ideal would have some role seems to me still worth keeping in our memory.

Jefferson had really looked forward to the possibility of agricultural sciences becoming an academic business. In one of his letters he said his ambition in founding the University of Virginia was to see that agricultural science is restored to its rightful position. Agricultural sicence, he said, should be the crown of all the sciences. He proposed that, "the same artificial means that have been used to produce a competition in learning may be equally successful in restoring agriculture to its primary dignity in the eyes of men. In every college and university a professorship of agriculture, and the class of its students, might be honored as the first." This was Jefferson's version, perhaps, of the special fellowship or the project grant.

Emerging Shortcomings

I HAVE a great deal of sympathy for the agrarian tradition, and I should not like to be thought of as against it. If I have any prejudice, it would be that I would like to know how to make the Jeffersonian vision a reality in a modern industrial civilization. And if I make any comments that suggest there are defects in the Department of Argriculture, I would much rather have you interpret them according to the formula Assistant Secretary Mehren used today: "merely pointing to substantial opportunities to heighten our own productivity."

A number of complaints are emerging in chorus.

First, it is said that agriculture ought to do more basic research. There does seem to be less of it going on in the Agriculture Department and under its auspicies than in some other places. At any rate, agricultural leaders themselves think there should be more of it.

Second, they seem to think that the Agriculture Department may be suffering by confining itself so nearly exclusively to the support of research in the land-grant universities in particular and public institutions in general.

Third, there is the belief that perhaps better results could be obtained if it were possible to concentrate a bit more on work of the highest quality and to put a little bit less on a great many detailed research programs in a great many small institutions.

Fourth, there is the chorus which says we can no longer look at the farm problems and agricultural productivity alone; we must range over the whole gamut of the national resources problem. We must look at the broader problems of science. We must look for initiative to go into new problems and for procedures that will let us push ahead into new problems.

I don't know whether these several types of complaints about our current policy are valid or not. Even though there seems to be some consensus in the directions I have mentioned, I think I detect a certain feeling of fatalism—a certain type of helplessness about it. But I would like to try to carry the diagnosis a step further, because I think there is a certain amount of politeness which still inhibits the communication between the National-Academy-of-Sciences types—if I may be crude in my terminology—and the Department of Agriculture as an organization.

First, I think that one has to look at the trends in basic science itself as a causative factor. About a century ago you could tell with some clarity what agricultural science was. It was not the same as industrial chemistry, nor physics, nor geology, or whatever. Jefferson could quite plausibly say, "argricultural sicence" and anybody knew what he meant. But today, because the basic sciences have become more abstract and more general in their interests, the dividing lines between the disciplines have become so blurred that it is no longer useful to try to distinguish them very neatly from each other.

The sciences, as they have gotten rid of the notion of teleology or purpose and became more mathematical, more abstract, have come to interlock and interchange much more effectively. This means that, whatever one thinks about the great majority of applied work to be supported, the advanced frontier, the cutting edge of the business, the highest quality work, is work which cuts across these boundaries and can be pushed effectively only by scientists of the very highest quality.

I must admit it bothered me to learn that the criterion for allocating research to nonland-grant universities is only when we can see that work of a particular nature can be done best by a particular institution. It seems to me that this is the exact reverse of a policy that might be followed if work of the highest quality is wanted in the institutions where the scientists of the highest ability can be found. It ought to be put there especially if you don't know what you want to do.

The Project System

I HAVE sat in a good many committee meetings where leading scientists talked about the project system and alternative systems of support. It seems to me that scientists like the project less because it lets them evade teaching responsibilities than because it lets them evade the supervision of their deans and presidents. That is to say, it lets them do precisely what they want to do and it prevents any necessity of fitting into a university program. This is why it seems to me that the main merit of the project system is not that it is particularly good at buying particular research, but that it is good because it lets panels of other scientists ignore what the dean thinks about it and ignore what the granting agency thinks about it, and it gives the scientists' club the right to give money to the colleagues that they respect the most to use on terms that they think most suitable.

I was incredulous when I first discovered that the main thing that held back a number of agencies of the Federal Government from paying full costs to universities was not congressional or bureaucratic prejudices. It was that the university professors themselves looked on any payments that went to their university administrations as a net subtraction from the money that they might have for research.

How did this business evolve shortly after the war? The project grant was the obvious successor of the wartime contract. Whether the grant or the contract was used as the mechanism seemed of symbolic importance to some people. But the net practical effect was mainly that in the contract you could pay full overhead and in the grant you couldn't. The degree of freedom was practically the same. If it had not been for competition among the military services, there would have been much less of a seller's market in brains, so to speak, in the years that followed the war. It had all of the bad results of free competition and over-pricing, but it *was* a seller's market in brains.

At the end of the war, looking at the results of the Manhattan Project and the OSRD, each of the military services first, and then the Atomic Energy Commission, and a good bit later the space agency, said in effect: "We are going to buy a good share of the scientific talent of the country on whatever terms we need to pay, and we are going to have them on our side. We are going to have them on our side merely to do research, because we really don't know what they are going to work on specifically, but because if we have their interest and attention, their graduate students will come along and

be devoted to problems which are of interest to us. And these will have profound effects on the future of our business, both with respect to the development of a whole body of basic research on which we can draw and also because we can draw on the young scientists for our civilian bureaucracy."

A Form of Federalism

THIS was, in the 1950's, a crude new counterpart of the Agriculture Department of the 1930's. But it was a new form of federalism. Instead of a single set of public educational institutions being committed to a particular department, it was a free competition among the executive departments for public and private institutions alike. It perhaps was a realistic recognition that careers in modern society could no longer be changed year by year according to the momentary activity of the particular individual; that more depth of knowledge was required for a professional career.

Just as the basic sciences have broken down the boundaries between them, so have the various aspects of technology. As a result of this breakdown, the boundaries between the executive departments are no longer neatly definable. This, of course, strikes at the heart of the faith on which I, as a public administrator, was brought up: you had to have neatly segmented departments with clear lines of authority and no overlapping in order to have responsible government.

How can we do that today? Let me just recount the subjects associated with agriculture today: Outdoor recreation, environmental health, nutrition, the synthesis of proteins, preservation of foods by irradiation, water resources, weather modification, and rain making. A fairly formidable list of technologies and sciences! Probably if you ask the average independent observer he would say that in none of them is agriculture clearly in the lead among the Federal departments with respect to the support of those disciplines that will be out on the frontier.

I think we have to talk not in terms of whether the agricultural research program has been a success—about which there is no question whatsoever—but whether the form of federalism to which the Agriculture Department is still committed enables it to compete adequately with other executive departments in looking toward those branches of research which are going to be the new frontiers of science and development in the future. It seems to me that this pattern commits the Department of Agriculture to a system which, in scientific terms, is unduly conservative. The governance of the scientific program is dominated by the colleges, the commodity groups, and the congressional committees. This is fine for the great bulk of the work. But it comes closer than I like to committing all of the program to "the requirements approach"—that is, work in fields that have been predetermined for the scientists by others. And if I were to have a philosophical difference with this approach, it would be on the following grounds:

Science in the modern world can no longer be merely a tool used by the political leader and the administrator to help him carry out policies and attain objectives that he has already defined. The administrator and the politician cannot have their full range of freedom of choice unless the scientists can tell them what options are going to be open that they had never imagined.

And so I would really like to see the Agriculture Department have more strings to its bow—more variety, more opportunity to go to any research institution and any university in the country, and to add to its initiative, its scope, and its independence by giving its best scientists a chance to work toward the department's broad objectives. It would do so either by institutional grants, or if you prefer, by project grants. As to that choice, I couldn't care less.

If anyone proposes such a system of discretionary

grants, the conventional reaction will surely be that this step would represent a diminution in congressional control. I don't think such delegation represents a diminution in congressional any more than in executive control. Only if both the Congress and the executive branch are willing to grant a measure of freedom and initiative to scientific institutions can those institutions do the kind of job that will justify their support at the highest levels. The old conventional proverb of administration was that scientists should be on tap, but not on top. This has never been true in the United States, and the Department of Agriculture is the best example of that.

Jeffersonian Philosophy

IF I were to try to reconstruct a philosophy of agrarianism for a modern age, I would appeal to Jefferson in action against Jefferson on paper. We ought to be able to rise to the highest level of using the highest type of science available in our society without regard to the institutional dogmas of the late 18th century. In short, if I were forced to profess a specific traditional political philosophy—which would be an uncomfortable position at best—I would be more tempted to start with the agrarian tradition than any other one I could think of. My philosophy has four essentials:

First, the ability of an administrative system to protect freedom by decentralizing within its own establishment.

Second, the predominance of the genuinely popular interest in our country against any form of privilege.

Third, a concern for the quality of our civilization against the accumulation of mere wealth or the enlargement of mere technical power.

Fourth, a faith that science still has the potentiality for being a force for liberation of the human spirit, rather than for its oppression of mankind.

These, it seems to me, have not been made obsolete by the new science, even though the new science may be forcing us to readjust many of our political institutions. And I hope the Department of Agriculture will long flourish and pursue the mission of supporting them.

Impact of Research

The impact of research upon the University is more than financial. The alliance between the university scholar and various groups from business, industry, and the federal government has not only extended knowledge about mankind and his world, but has also helped improve the University's libraries and laboratories. The student benefits from the insights and the intellectual stimulation gained by the professor in his research. In the graduate laboratories, the student and the professor often stand side by side, sharing the hard work and the occasional excitement of discovery. In fact, at the University, it is required that the researcher also be a teacher.

In the final analysis, the citizens of Rhode Island also profited last year from the work going on in the libraries and laboratories. Just a few examples suggest the variety of activities: an economist developed data to facilitate better planning for use of the region's marine resources; a horticulturist bred what may be a cold-resistant tomato plant; a civil engineer found a chemical-cement mixture that can be used to produce better road beds; an oceanographer obtained new types of measurements of the Gulf Stream, a generator of some of our weather; and a political scientist completed a study of the factors determining the selection of city and town managers.

From: University of Rhode Island
Annual Report 1964–65

PHILIP HANDLER

Fundamental Research and Progress in Agriculture

MOST of us here share the conviction that population control is imperative if human civilization is to have quality discernibly different from brute animal existence. But achieving the necessary control is a long and difficult task. Indeed, it is optimistic to consider that the population of this planet can be stabilized reasonably soon after the turn of the century.

Accordingly, we cannot escape the prospect that world agriculture must ready itself for the task of more than doubling its output over the next 35 years. But double what? And how?

Optimum Nutrition

IN viewing the future of American agriculture, we commence from a position of great strength, as we are all aware, of a readily available surplus in the soil bank. From the standpoint of the planet, however, we look to the future from a position of weakness and an awareness that world agriculture, even now, is insufficient to world need.

Part of the difficulty of making projections is the uncertainty as to what constitutes optimum human nutrition. Most of us are convinced that the only significant nutritional problem within our own country is that of surfeit. But, even here, we have not successfully dissected the alleged defects of our hypernutrition from the physiological consequences of our own way of life.

Abroad, matters are simpler. One can readily identify the consequences of chronic undernutrition. This is readily seen in the increased stature of second and third generation Asiatics and Europeans from the Mediterranean basin when they have the opportunity of eating Western European or American diets. Across the tropical belts protein insufficiency is distinctly visible in its acute form as kwashiorkor. Vitamin A deficiency can still be seen on a large scale in some parts of the world, and ironically, as in Malaysia, these are the greenest parts of the world.

But strangely, there is disagreement concerning the nature and the level of the protein and the diet required to prevent deficiencies. Available esti-

mates, nevertheless, suggest that the world caloric production is presently too low by 10 or 15 percent. World protein production may be too low for the current population by perhaps 25 percent.

A large fraction of the world's population lives on an essentially vegetable diet. But this is the fraction which is also undernourished; hence an appraisal of the effects of vegetarianism is hazardous. Although it has been repeatedly demonstrated that an appropriate mixture of vegetable proteins can supply a nutritionally adequate mixture of essential amino acids and vitamins, much of the world's population which subsists on vegetable foods is also frequently restricted to one or two major vegetables.

Insistence upon animal protein is, of course, a highly expensive notion, since about seven calories accumulated by photosynthesis are required to yield one calorie of animal food. However, we can hope that at least a modest amount of animal food can be made available to all men in the not too distant future. If we accept this as a reasonable goal, then by the year 2000 total food production of all types must increase by approximately 150 percent and animal foods by over 200 percent.

I must repeat my earlier caveat: Our knowledge of optimal human nutrition is primitive and we badly require a rational basis for gross agricultural planning.

Productivity of Land

LET us assume that we can manage to stabilize the world's human population at between 6 and 10 billion. By what means, then, can we improve the productivity of land currently under cultivation; and how can we bring additional land under cultivation? Some of the arithmetic is fairly simple. Slightly less than one-tenth of the world's land area is currently in cultivation. Perhaps three times that area is used as pasture. Therefore, about one-fourth of the land area is being utilized for food production. Unfortunately, of course, most of that land area has been despoiled and abused, and in this country about 300 or 400 million acres of crop or rangeland have been removed from productivity. Hopefully this process can be halted. But we cannot readily halt the retirement from production of about a million acres a year in this country of the land which becomes suburbs, shopping centers, subdivisions or airports.

Most of the world's agricultural production comes from areas which were originally prairie, steppe, or broadleaf forest. Presumably, most such areas are presently under cultivation wherever the terrain has permitted, so that one cannot look forward to any major expansion of agriculture in such regions. To open new soil around the globe on a large scale will require using soil types which heretofore have not been extensively employed. The most appropriate candidates are (a) the soils that have evolved mainly under coniferous forests and in relatively cool climates which have given rise to the podsols and (b) the lateric soils of the tropics. The practical problem of using such soils for intensive agriculture is enormous. But presumably it is not insurmountable. Only a fraction of the 10 billion acres, of course, could be put into production, because much of it is either in productive forests or unavailable because of its terrain.

The productivity of at least another billion acres currently in production could be significantly increased if sufficient water were available. In addition, several hundred million acres of desert are potentially productive if adequate water resources can be found. A considerable fraction of this area lies within the United States. Whether that possibility will be brought to fruition by water generated by rain-making, brought in by pipeline from considerably more northern regions, or pumped in from desalination plants, one cannot yet say. But it is true that we are not prepared for that time.

Effective Use of Technology

THE sum of these activities would probably meet the emergency we have in view—doubling the world population by the turn of the century. But it is a large-scale process requiring an enormous expenditure of effort and of capital. Therefore, we must ask what we can expect by application of science and technology to land already in production. Whether we Americans use our agriculture to meet the food problems of the world until other nations can meet their own problems, or whether we simply look forward to the growth of our own population, it behooves this Nation to insure its agricultural productivity for the future.

A majority of the world's people today find most of their sustenance from only about a dozen species of plants. These are the historical legacy of man's

attempts to feed himself from the wild plants which have populated the earth. The magnitude of man's dependence on a few crops is really appalling. At least half of the world's people derive more than 60 percent of their energy from rice alone. Stated another way, more than 30 percent of all human energy comes from this one species—the rice plant.

Ponder, therefore, the consequences of a rapidly spreading rice predator, or the rice equivalent of the chestnut or elm blight.

It appears ever more urgent that agricultural and botanical research be pursued with a maximum vigor to meet the production goals for the next century. If scientific agriculture is to flourish, the science upon which it rests must flourish also. Those responsible for our national program in agriculture must accept responsibility for support of fundamental research in the sciences which underpin it.

This cannot be done by restricting support to the inhouse laboratories of the USDA—no matter how liberal their research policies—nor to the agricultural experiment stations at the land-grant universities. There must also be a vigorous program of support for the well-springs of related science, regardless of where these may be. As a dividend, bonds are created between the USDA and first-rate academic scientists the Nation over. And they may well prove to be agriculture's most precious resource!

Areas of Needed Research

WHAT areas of research appear to be significant at this time and most likely to produce understanding which can be translated into useful agricultural practice? In seeking answers to this question I have borrowed freely from an advance copy of the Report on the Plant Sciences prepared by a subcommittee of the Committee on Science and Public Policy of the Academy.

1. Chemical weed killing bids fair to eliminate one of the most ancient and backbreaking of man's agricultural labors. Research must continue to unravel the secrets of plant physiology in the hope that new leads will open the way to specific weed killers, and to phenomena and application of which we have no vision at this moment.

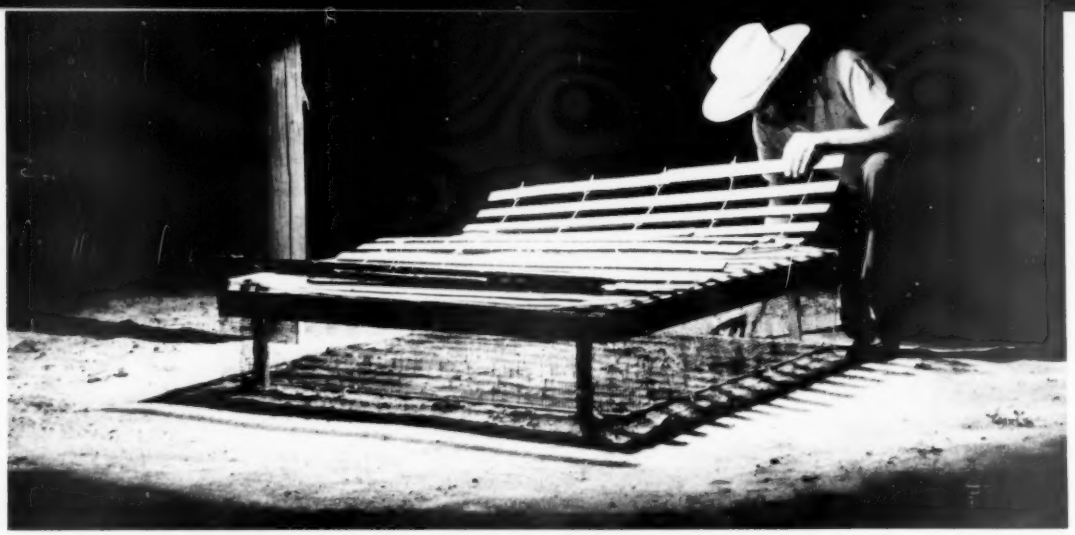
2. The exciting work led largely by Sterling Hendricks at Beltsville has opened new vistas of understanding of the light-detecting systems of plants and the manner in which they operate to control the time of flowering. It seems entirely possible that pursuit of these mechanisms may yet make possible external control of the flowering process, for example, by chemical sprays.

3. Understanding of plant endocrinology is as yet quite primitive. Further integrated studies offer the opportunity of much more precise control of plant culture.

4. Cultivation of intact plants from single cells has been demonstrated in the laboratory and opens the possibility of revolutionary approaches to plant propagation and genetic manipulation.

5. The ochre mutant of maize which has an unusual abundance of lysine has been much publicized. Undoubtedly, a strain of corn with an amino acid composition more closely approximating the balanced mixture required by man would be an enormous boon to mankind. The same approach should systematically be pursued for other plant forms—even wheat and rice.

6. There should be a continuing cataloging and examination of the possibilities for human nutrition of the thousands of plant species which have hitherto not been considered. Indeed, it is about



time to plan, on paper, the perfect food crop and breed toward it from the most appropriate starting material.

7. Hybrid vigor or "heterosis" is incompletely understood and does not operate consistently in the desired fashion. Surely the biology of heterosis is deserving of the most intensive attention.

8. Each of the principal food crops warrants intensive study with respect to nutrition, conditions of culture, and the continuing development of new strains.

9. Research should be stepped up in seeking genetic strains with minimal requirements for water and searching for agents which can alter stomatal physiology to reduce water requirements.

10. Only a small fraction of the total plant cover of the planet is potentially available as human food. We utilize mainly seed parts, whereas the leaf—the chemical factory of the plant—is rich in vitamins, minerals, and its proteins. Surely this justifies a vigorous program for new technology whereby the components of the leaf can be made available as a supplement to the human dietary.

11. In our country the time is far off before we need contemplate developing the use of algae as primary food for man. But algae may very well hold the answer to how we shall manage to continue to enjoy something like our current bountiful supply of animal protein.

12. No creature has so altered the ecology of his surroundings as has man himself. Our understanding of the ecology systems, both small and large, are rather dim. It behooves us to continually refine our ecological understanding if we are to avert disaster as, by diverse procedures, we attempt to control our environment.

13. The science of entomology has contributed much to agriculture. But for more than a generation this science had become almost moribund. The use of chemical insecticides in the last several years has resulted in a small renaissance in this discipline, if you will. But surely the efforts to date have been insufficient; our approaches to insect and pest control generally must certainly be in their infancy. If more efficient and effective chemical weapons are to be designed for this arsenal, it can only be done with a much more intimate understanding of the anatomy, physiology, development, and behavior of the insect forms with which we are concerned.

As a biologist it is my hope that with sufficient understanding we can minimize the use of chemical pesticides. In the end, we shall probably be forced to compromise between the hope of total eradication of a pest with a chemical and settle for biological control which is unlikely to be complete but can reduce damage to an acceptable minimum.

* * *

Much must be done if we are to provide the scientific underpinnings of a modern agricultural technology. The sophistication of that technology to date is the platform on which rests the remarkable affluence and sense of well-being of American society as it enters the age of scientific revolution. It is that technology which has made it possible for 1 man to feed 20 of his fellows—freeing those fellows to develop still other technologies or to explore beckoning avenues of the spirit and of the mind. If it be at all possible, we must offer that same prospect to our children's children—not only in our own land, but in all the far corners of the earth.

Organizing Research for Social and Economic Objectives

an outsider's appraisal of the strengths and weaknesses of agricultural research

HARVEY BROOKS

ONE might express the relationship between science and society succinctly as follows: Society wants results, and scientists want support and freedom. Society has increasingly realized that if it wants results it must accord scientists at least a degree of freedom to pursue their own objectives in their own way. On the other hand, scientists are beginning to realize that they cannot expect continuing freedom and support unless at least some of them concern themselves with translating the findings of science into things society wants and can appreciate.

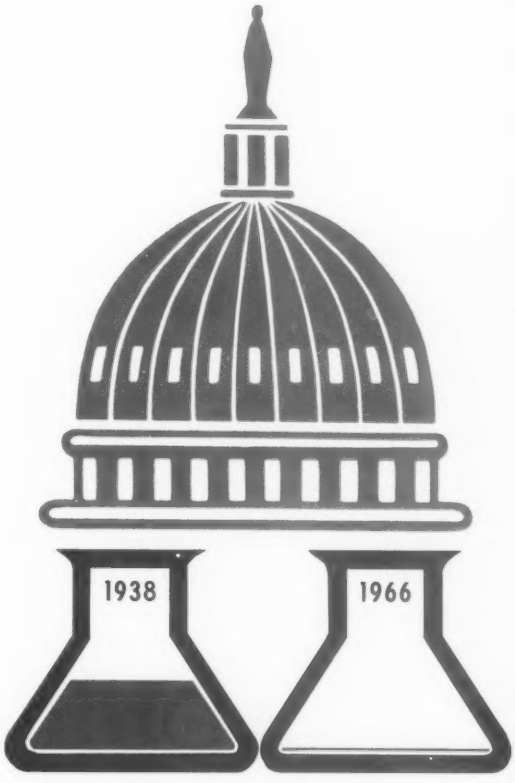
Throughout the world, it seems to be an accepted article of faith that science and technology will save us. But there is remarkably little understanding of how this magical process will occur.

What could be more natural, then, to turn first to the greatest of the success stories of the translation of science into successful application—agricultural research—to see what lessons can be learned. In attempting to draw these lessons, we must not fall into the trap of relying too much on history. In science and technology nothing fails like success. History is waiting to clobber the successful scientist or engineer who looks confidently into the future, and, on the basis of his past experience and reputation, predicts what will and will not work.

The Changing Patterns

AGRICULTURAL research today exists in a far different environment than it did 30 years ago. In 1938 agricultural research amounted to 40 percent of all federally-supported research and development. Today, although far larger and more diverse, it is less than 1.6 percent of federally-supported research and development. Perhaps more to the point, it is probably no more than 10 percent of federally-supported research in the life sciences. Its share of the most highly trained manpower in the sciences is probably substantially less than this.

Essentially one can almost say that Federal research and development didn't exist prior to the Civil War. Federal involvement in science and



the application of science began seriously in the 1870's. As a matter of fact, the National Academy of Sciences played an important stimulating role in this development. Early Federal science was closely tied to clearly defined social objectives—food production, the finding of natural resources, the establishment of industrial standards.

Agriculture existed as a scientific discipline in its own right. Only a few general principles extended beyond the confines of agricultural science, chiefly the Mendelian laws and the principles of evolution. For the rest, the content of the science was defined by particular objects of study—the economically useful plants and the specific parasites which preyed on them. This was an era of science which was largely descriptive. I think agriculture is typical of other examples such as the Geological Survey, Bureau of Mines, and Fish and Wildlife Service. The techniques were primarily those of observation rather than of experimentation.

To further contrast the old and the new pattern in Government science, I offer a series of parallel statements in which the generalizations, I think, have some validity.

In the first place, the old pattern was largely in-house research. On the other hand, a characteristic of the new pattern is a very large delegation of initiative to the private sector.

The old pattern was one of a high degree of dispersion of research efforts both geographically and in many small research units. The new pattern is considerably more concentrated. For example, about 50 percent of R&D funds is spent in 5 private corporations and about 50 percent of university research funds is spent in about 20 universities.

The old pattern was primarily institutionally oriented. The new pattern is primarily program and project oriented.

The old pattern was market-directed, whereas the new pattern might be called science or technology directed.

The old pattern was characterized by rather close congressional scrutiny and control; the new pattern by rather weak congressional control and much stronger executive control.

The old pattern was weakly coupled to the external technical community; the new pattern is strongly coupled to the non-Government scientific community.

One might say that the old pattern was a need-oriented organization. One only has to look at the research program of the Department of Agriculture to see its very strong orientation towards the needs of the various groups which it serves. The new pattern is what I would call opportunity-oriented—that is, it centers in science and looks towards the way scientific projects can serve needs rather than starting with needs and looking at how science can serve those needs.

The old pattern tended to do something with all the relevant technologies; the new pattern tends towards greater selectivity.

The New Clientele

Of course, I have overdrawn these differences. In many respects they are not simply characteristics of the old and the new; they are also characteristics of the different clientele which is served. In defense and space, for example, only a very few key decisionmakers really h a v e to be convinced. Whereas in agriculture you have to convince a very wide group of farmers. The clientele in health research is mainly the researchers, not practicing physicians. Congress was clearly convinced by the wartime pattern that the opportunity-oriented approach was superior.

Can we say anything about the comparative merits of these two patterns? One might argue that they are simply appropriate social adaptations to the national goals which they serve. Or one can go to the opposite extreme and argue that the difference in pattern is entirely historical. The agricultural pattern dates from the era of a weak executive, of "little" Government, if you will, with a high degree of influence of local and regional interests. The so-called modern pattern dates from the era of the strong executive, somewhat weakening congressional control, growing influence of outside experts, and powerful internal bureaucracies, plus a general tendency of Congress to be much more permissive with respect to anything that touched on national security than in other fields.

Are there any measures of success of one pattern over the other? Clearly for the pattern of agriculture the criteria of success are quite evident. The productivity increases in agriculture and forestry have exceeded any other economic sector so far as I know, and this has been the trend for something like 50 years. At the same time we have suc-

ceeded in conserving and building up our potential productivity even faster than our actual productivity. I have heard economists seriously argue that agricultural research has been a dismal failure, because productivity research has built up surpluses at rather large national cost while utilization research has failed to find ways of consuming them and economic research has failed to find ways of spiriting them away. But in the context of the world with which we are faced today, with two-thirds of the world's population underfed, I cannot believe it was a national mistake to build up our productive resources and our potentiality for future production.

Another point I have sometimes heard is that agricultural research didn't really pay off until scientific developments outside agriculture were exploited—such as pesticides, antibiotics, and the applications of radio-activity. However, this argument doesn't impress me too much because it would not have been possible to exploit these developments from outside agriculture if a magnificent organization for applying and diffusing technology had not already existed in the agricultural organization. Furthermore, the production of antibiotics on a large scale was not possible until the fermentation laboratory of the U.S. Department of Agriculture showed people how to actually produce penicillin.

It is much harder to find cost-benefit criteria for other research areas, because most of the federally-supported research is directed towards noneconomic goals and we have no objective system of social accounts analogous to our national income accounts with which to measure its effects. It is true our health has improved, but, by statistical measures, several other countries spend considerably less money on health research and yet have better statistics than we do. In fact, some people believe we have failed to maximally utilize the results of research that we have so magnificently produced in improved health care. In other words, the coupling problem has been relatively neglected in the health field so that the progress of science may have outrun our capacity to organize and apply it.

The trend that I see now—and which I think is desirable—is the tendency for both systems, the modern and the old, to evolve towards each other.

Goals for Agriculture

WHAT, then, are the directions desirable for agriculture? I think there is a real need for a more opportunity-oriented approach to agricultural research such as the pioneering laboratories of the Agriculture Department. One might describe this crudely as solutions looking for problems, rather than problems looking for solutions. It is customary to make fun sometimes of solutions looking for problems. Nevertheless, many of the biggest steps forward in the application of science have often come from this approach.

Secondly, I think the Agriculture Department should make greater efforts to enlist the interest and participation of the wider scientific community in agricultural problems, the nonagricultural parts of universities, the fundamental science departments. To do this successfully requires that agricultural missions not be interpreted too narrowly.

Third, I think we need a reformulation and restatement of agricultural missions in a way which is more challenging to the young scientist of today. Not many young scientists are challenged by improving the quality of peanut oil. But most of the young biologists, even the very fundamentally oriented biologists, are passionately concerned about the world food crisis and its ultimate solution.

Some believe rather naively that basic research will solve problems automatically if the results are simply made available. To some extent we probably have to tolerate this naivete provided we are not bemused by it.

We must find ways to mobilize efforts on more broadly defined and more functionally defined problems, and support a higher proportion of research for which the application is uncertain or at least not obvious. I am not suggesting that we should dismantle the tightly coupled system that we have developed in agricultural research over the years—that is, the tight coupling to the social and economic objectives which it serves. Rather, I think we should try to strengthen these, while striking deeper roots into the scientific community.

THE AUTHORS

SELMAN A. WAKSMAN ("Microbes and the Survival of Man on Earth") is Emeritus Professor, Institute of Microbiology, Rutgers University, N.J. A native of Russia, he received his academic degrees at Rutgers (1915, 1916) and the University of California (1918). In addition, he has been awarded more than a score of honorary degrees by universities both here and abroad. He began his career as a lecturer in soil microbiology at Rutgers in 1918, and was made professor in 1930. He became head of the Department of Microbiology in 1940. In 1949 he was appointed Director of the Institute of Microbiology. He retired in 1958 as Director of the Institute and as Professor of Microbiology. During that period he also served as consultant for many public and private research institutions. Dr. Waksman is perhaps best known for his research on the soil actinomycetes and the isolation of various antibiotics, including actinomycin, streptomycin, and neomycin from soil microbes. His work has brought him many honors, the most notable being the Nobel Prize in Physiology or Medicine awarded in 1952.

ERNEST T. SMERDON ("Water Development and the Agricultural Sciences") is Director of the Water Resources Institute, Texas A&M University, College Station, Tex. He received his B.S. degree from the University of Missouri (1951) and his M.S. (1956) and Ph. D. (1959) from the same institution. For a year, in 1951–52, he studied graduate meteorology at the University of Washington and was a weather forecaster for the following 3 years. He taught and did research at the University of Missouri in 1957–58 prior to going to Texas A&M University in 1959. Dr. Smerdon's research is in the area of irrigation hydraulics, erosion of cohesive soils, and water supply.

DANIEL G. ALDRICH, Jr. ("Agricultural Research: A Key To Understanding Our Environment") is Chancellor, University of California, Irvine. A graduate of Rhode Island State College, he obtained his M.S. from University of Arizona in 1941 and his Ph. D. from the University of Wisconsin in 1943. After a tour of military duty, he joined the California staff in 1946 as an assistant chemist, progressing to the position of University Dean of Agriculture, Berkeley, in 1959. Dr. Aldrich became chancellor of the Irvine campus in 1962.

DON K. PRICE ("The Agrarian Tradition and the New Science") is Dean, Graduate School of Public Administration, Harvard University, and president-elect, American Association for the Advancement of Science. He holds degrees from Vanderbilt University and Oxford and has been awarded honorary degrees from several universities including Harvard. His wide experience in public administration work includes 7 years as associate director of the Public Administration Clearing House and 6 years as vice president of the Ford Foundation. He has served on the Bureau of the Budget; the Research and Development Board, Department of Defense; and on several presidential advisory committees. Dean Price has authored several books on public administration, science, and Government affairs.

PHILIP HANDLER ("Fundamental Research and Progress in Agriculture") is chairman, Department of Biochemistry, Duke University Medical Center. He was graduated from City College of N.Y. and received graduate degrees from the University of Illinois. A former chemist for the Department of Agriculture, Dr. Handler joined the Duke faculty in 1939 and assumed his present position in 1950. He has served as consultant for a host of public and private agencies, as President of the American Society of Biological Chemists, and of the Federation of Amer. Soc. for Exper. Biol., and is presently a member of the President's Science Advisory Committee and the chairman of the National Science Board, N.S.F.

HARVEY BROOKS ("Organizing Research for Social and Economic Objectives") is Dean, Division of Engineering and Applied Physics, Harvard University, and chairman, NAS Committee on Science and Public Policy. Educated at both Yale and Harvard, Dr. Brooks also holds honorary degrees from a number of colleges and universities. He joined the Harvard staff in 1950 and assumed his present position in 1957. He is editor-in-chief of the Journal of Physics and Chemistry Solids, and a former member of the President's Science Advisory Committee, in addition to serving as consultant to various agencies in the areas of solid state physics, underwater sound, and nuclear reactors.

U.S. GOVERNMENT PRINTING OFFICE: 1966 O—219-743

AGRICULTURAL SCIENCE REVIEW is a critical review journal designed to provide a common point of understanding among agricultural scientists by publishing authoritative commentary on the current state of agricultural research. *Review* does not publish primary research reports. Yearly subscription rate is $1.25, domestic; $1.50, foreign. Single copies are 35 cents. Subscription orders should be sent to the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.